

System Implications of Implementing Auto-Exposure on Consumer Digital Cameras

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ABSTRACT

In consumer digital cameras, some of the primary tasks in the image capture data path include automatic focus, automatic exposure (AE) determination and auto-white balance. There are numerous algorithms used in implementing these tasks – auto-focus is implemented using maximum contrast, ranging or sonar; white balance using color gamut determinations and “gray value estimations”, and auto-exposure using scene evaluations. We evaluate the system implications of implementing one of these tasks, namely auto-exposure on an embedded system – a digital camera. These include, among other things, design approach, power consumption, software vs. hardware implementation and microprocessor vs. ASIC implementation. Commercially available digital cameras and their choice of AE implementation are discussed where appropriate. Such an evaluation will assist, we hope, anyone designing or building a digital camera *sub-system*.

Keywords: Digital Camera, Camera Design, Camera implementation, Auto Exposure, Matrix metering

1. INTRODUCTION

In a digital camera image-processing pipeline, one of primary tasks the system must accomplish is in the image pre-processing stage (as shown in Figure 1). This stage must set the system up for the correct focus, exposure and white balance *before* the shutter is released. The design approach and components chosen to implement these pre-processing functions have implications on overall power consumption, shutter latency (time between the pressing of the shutter and when an image is captured) and final image quality. We will discuss these and related issues with respect to one image pre-processing function – auto-exposure (AE).

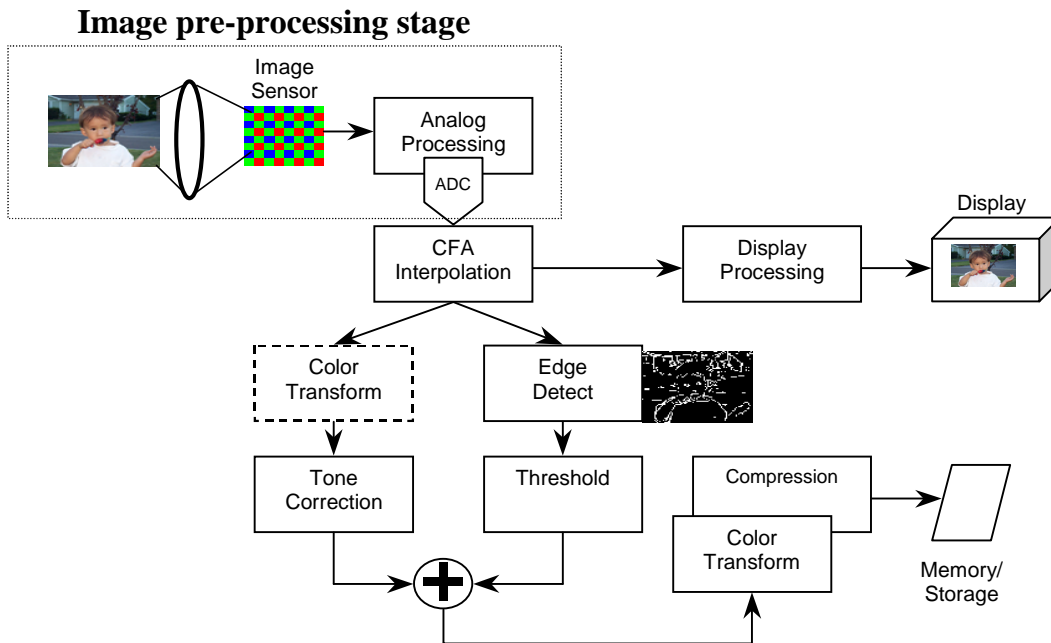


Figure 1: Image processing pipeline in a digital camera

Figure 2 is another view of the image pre-processing stage, expanded to show the details of the analog image processing chain found in a typical CCD sensor digital camera.

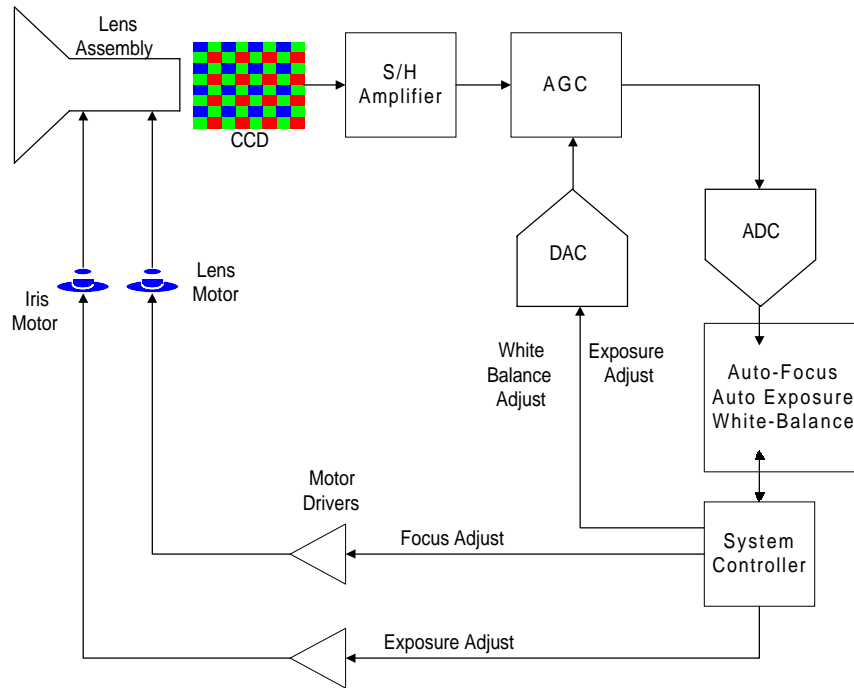


Figure 2: Expanded view of the image *pre-processing* stage

2. PRIOR ART – PATENT LITERATURE SEARCH

There are several reasons for reviewing patent literature. Prior to understanding a technical investigation or product development, a careful review of patents and other literature can help us learn what others have already achieved, to avoid repetition and reduce time-to-market. The patents are classified into class/subclass structure, which helps to cross-reference against a particular category as described in Table 1:

Category	Class	Subclass
Camera	354	288
Automatic Exposure Control	354	410+
Automatic Focus	354	400+
Camera Shutter	354	226+

Table 1: Patent Classification

Patent classification search performed using IBM’s Intellectual Property Network against “automatic exposure” in the title would rate the leading camera manufacturer assignees as follows - Nikon Corporation (20), Canon Kabushiki Kaisha (19) and Eastman Kodak Company (9).

A typical patent implementation is initiated after the acquisition of a field from the CCD, the camera determines the color temperature of the light, amount of light and distribution of light in the scene. The basic algorithm for exposure calculation involves classification of the scene on the basis of the maximum luminance values and the span between the maximum and minimum values. Depending on the type of scene as determined by this process, sets of coefficients are chosen which are used to produce weighted averages of the various luminance measures of the scene. Armed with this information and focal distance of the lens, the camera uses look-up tables to classify the scene (e.g. morning daylight landscape, mid-day portrait, close-up fluorescent lighting, etc.). In this way, the proper average exposure can be determined based on the perceived scene.

2. THE AUTOMATIC EXPOSURE SUB-SYSTEM

The main objective of an AE system is to compute the correct exposure necessary to record an acceptable image in the camera. The process involves three steps – Light metering, Scene analysis and Exposure compensation.

- 2.1. *Light metering*: Light metering is generally accomplished using CdS (Cadmium Sulphide) or SPD (Silicon Photo Diode) detectors. The SPD is faster in response than the CdS and has no memory effect but costs more. The SPD’s sensitivity is also better suited for high light levels while the CdS is better suited for medium to high light levels. The exposure detector may be separate from the imaging sensor (typically a Charge-coupled device (CCD)) or the CCD itself can also be used as the exposure detector. Most digital cameras today use the CCD sensor as their *ambient light detector* and a separate SPD for detecting whether a flash may be necessary (“flash detection”). Kodak uses CdS as its ambient light detector and SPD as the flash detector in its DC-260 model as shown in Figure 3.

Camera	Flash Light Metering	Ambient Light Metering	Methods
Casio QV-5000SX	Silicon photodiode	Imaging CCD	Scene averaged
Kodak DC260, DC210	Silicon photodiode	CdS photoresistor	Separate sensors for reflected light ambient and flash
Fuji MX-700	Silicon photodiode	Imaging CCD	Scene averaged
Olympus D-600L	None	Imaging CCD	Scene averaged or center spot from main CCD
Nikon Coolpix 900	Silicon photodiode	Imaging CCD	Spot, center-weighted average and matrix metering

Table 2: Light metering methodology of several recent megapixel digital and film cameras.



Figure 3: Kodak DC260 (A-Ambient light sensor, B-Flash sensor, C-Autofocus sensor, D-Self timer light)

- 2.2. *Scene analysis*: Scene analysis (sometimes called *matrix metering*) involves segmenting the scene into different segments and weighting each segment appropriately to calculate an exposure to match the application in question.

For example, *center-weighted* exposure is used when the application dictates that the important segment is the one in the center of the viewfinder. Scene segmentation assumes that the light detecting sensor is two-dimensional and was first introduced in Nikon FA cameras in 1983. The process of auto-exposure using this technique is shown in Figure 4. Ambient light metering using a single sensor is similar to a separate light meter used in combination with a film camera. However, with the sensor fixed to the camera, it is not possible to provide exposure compensation for 'difficult' scenes that, for example, are strongly backlit, spot lit, or highly reflective (like sand or snow).

AE can also be performed using a specialized microprocessor solution as provided by Philips Semiconductors SAA9740H solution. It is a single chip that provides full digital auto-focus, AE and auto-white balance control. The size and placement of the center window based upon the light condition can be controlled via the microprocessor.

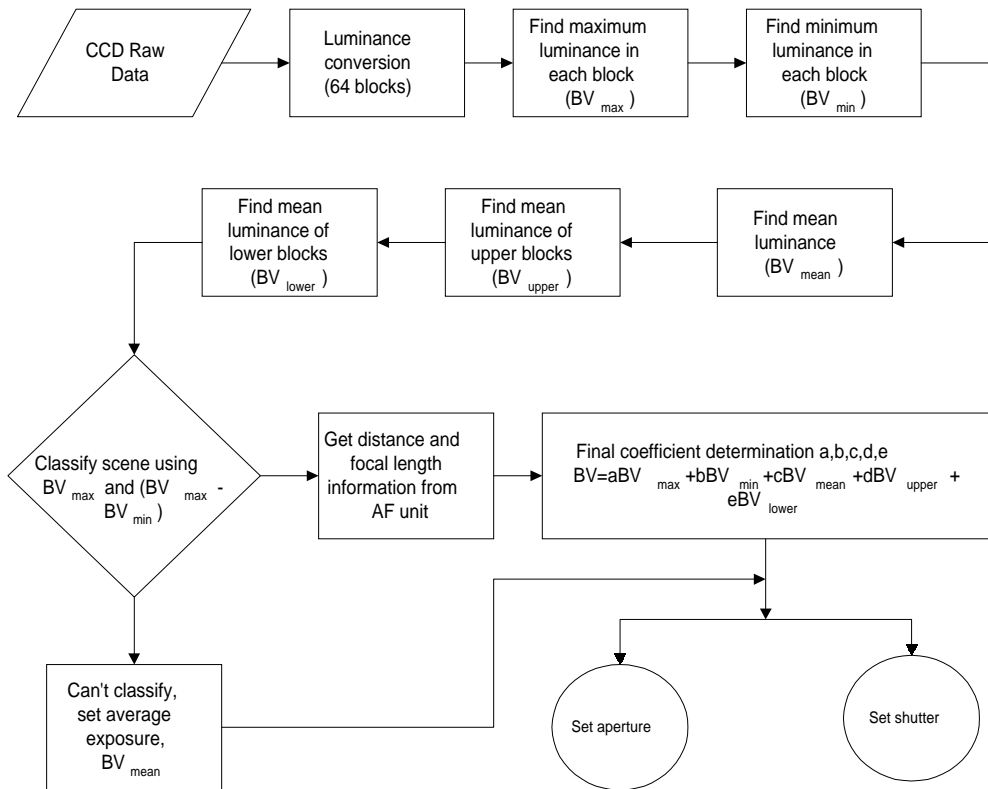


Figure 4: Sample algorithm using scene segmentation in automatic exposure development

- 2.3. *Exposure compensation*: To ensure that the correct amount of light reaches the sensor (exposure compensation), the AE sub-system manipulates a number of camera controls at its disposal – namely, the lens aperture (or iris), the shutter speed, and the gain control on the AGC (automatic gain control) device. Figure 5 shows the typical components of an automatic exposure sub-system that uses CCD as AE light sensor.

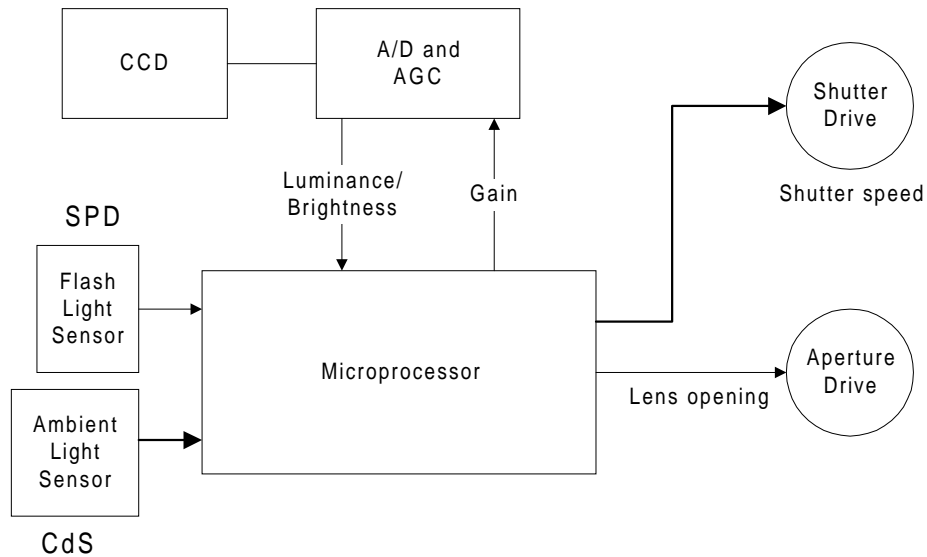


Figure 5: Expanded view of an AE subsystem

3. TWO APPROACHES FOR AUTOMATIC EXPOSURE IMPLEMENTATION

There are two approaches commonly used in implementing automatic exposure. For the sake of our discussion, we will refer to them as *optics-centric* and *electronics-centric*. The differences in the two approaches are characterized by the following design decisions:

- Detectors used for sensing the scene illumination
- Controls used for adjusting the exposure level
- View finders

In the *optics-centric* approach, an independent sensor detects light and the exposure is adjusted by closing the iris or controlling the time the shutter is kept open. This method is used in film cameras and in some digital camera systems. In the *electronics-centric* approach, the imaging sensor also meters the available light through the lens, the exposures adjusted by varying the integration time of the sensor and the gain of amplifiers in the analog channel prior to digitization.

Both of these systems have been derived from years of experience with film camera auto-exposure systems in point-and-shoot, SLR and camcorder devices. In digital cameras, hybrid approaches have also been employed using a combination of shutter/iris and integration time adjustment, with multiple light level sensors that can include the imaging CCD and auxiliary solid state detectors. *Optics-centric* film cameras have the additional free parameter of film speed, which allows scene capture over a wider range of lighting conditions than would be possible with a fixed sensitivity detector.

4. OPTICS-ENTRIC APPROACH AND ITS SYSTEM IMPLICATIONS

A typical *optics-centric* auto exposure system is shown in Figure 6. The system consists of two parts, one part controlling the flash output and one part controlling both flash use (in 'auto' flash mode) and exposure during photography without the flash. (One recent camera employing this AE methodology is the Kodak DC260).

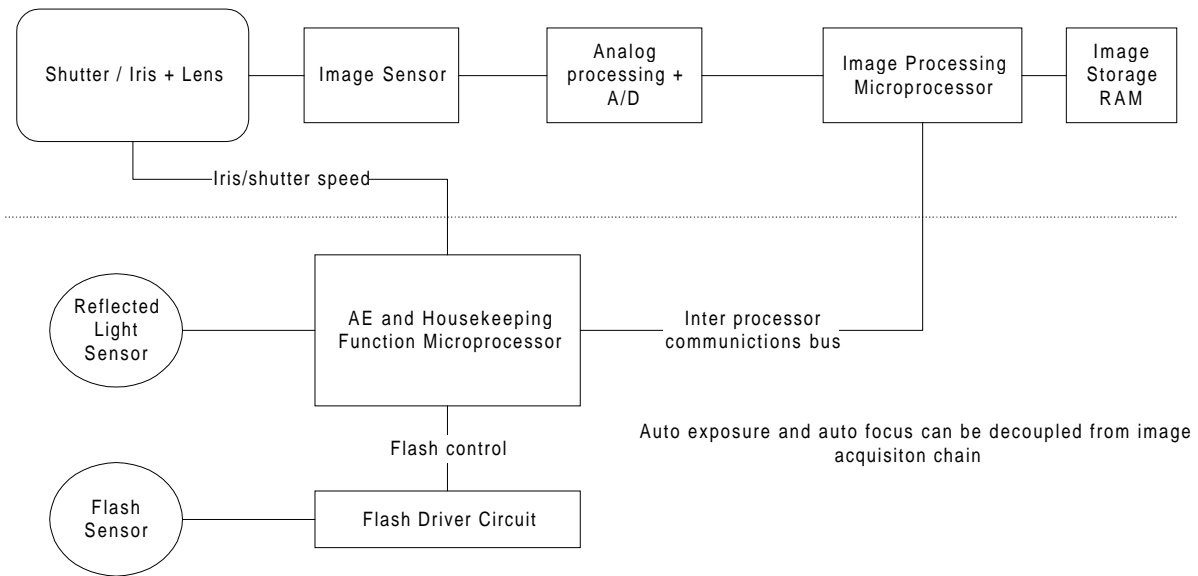


Figure 6: Optics-centric AE system typified in the Kodak DC260

The key elements in the *optics-centric* approach are a light sensor with known response as a function of light level, a method to measure the output of the sensor, and a microprocessor to control the mechanical components (shutter and iris or shutter-iris combination). Aside from the presence of a microprocessor, this system is very similar to conventional electronic photographic light meters that have been in use since 1932. Frequently, the light sensor is a CdS photoresistive cell that is more photometric in its spectral response than silicon photodiodes. Since the response time of CdS cells is slow compared to the flash duration, the flash must be metered by a separate system, usually a silicon photodiode.

After the camera is turned on, the camera can enter a dormant state consuming very little power. When the shutter button is depressed 1/2 way, the metering system is activated, and within a few milliseconds the reflected light from the subject is calculated. Auto-focus may also take place during this time period, employing contrast detection (using the imaging CCD) or various range-measurement systems. The ambient metering system also determines whether the flash should be activated in the 'auto' flash mode. The system then sets the 'program' or combination of shutter and aperture, in the electronically controlled intra-lens shutter. The inexpensive shutter units used in digital cameras and many point-and-shoot film cameras are often momentum-limited. That is, as the shutter speed increases, the maximum opening that can be obtained becomes less and less because of the inertia of the shutter leaves and the low power capability of the drive circuitry.

Because light level measurement and shutter/iris adjustment can take place independently and in parallel with auto-focus operations, this system has less potential *shutter press latency* (period of time between shutter button depression and image acquisition) than the *electronics-centric* approach.

6. ELECTRONICS-CENTRIC APPROACH AND ITS SYSTEM IMPLICATIONS

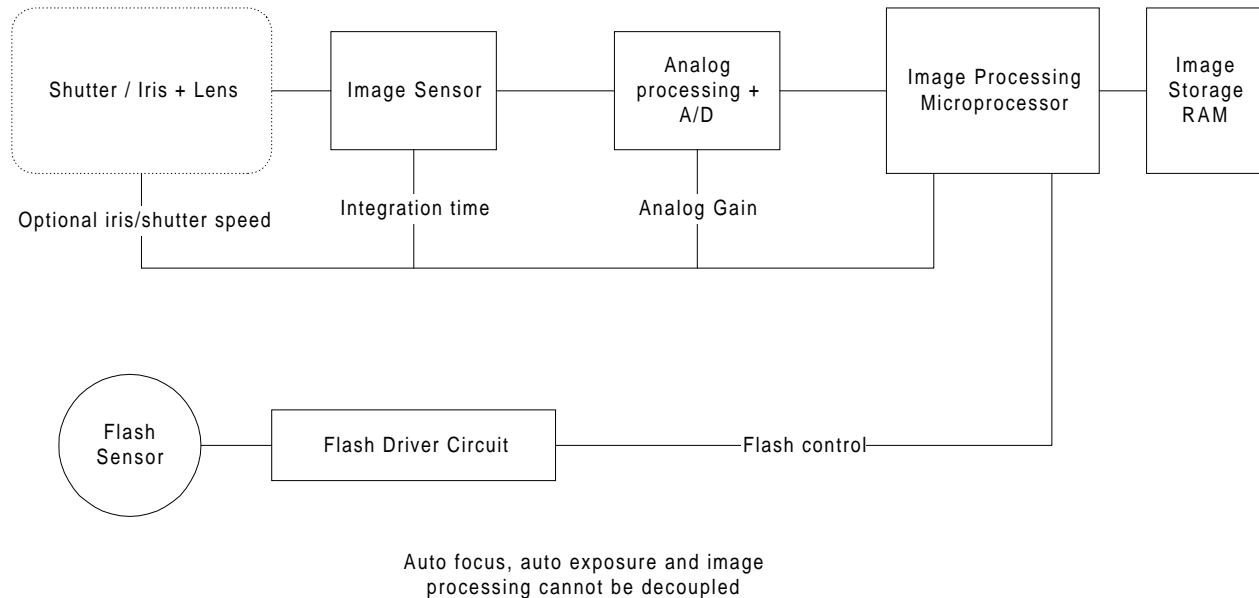


Figure 7: Electronics-centric AE system typified in the Nikon Coolpix 900

A block diagram of the *electronics-centric* approach is shown in Figure 7. This approach to auto exposure is derived from both SLR film cameras and camcorders. In digital cameras, a shutter/iris may still be used in combination with electronic shuttering of the sensor.

In high-end SLRs, area sensors are sometimes used at an equivalent film plane to sample the light from the image in multiple areas. Information gathered from this sensor is used to adjust the shutter and iris that is typical in the image chain of these cameras. Because the image is dissected into many different sub-fields, additional scene classification can take place with this system resulting in more accurate exposure than is possible with a simple reflected light meter. Similarly, camcorders adjust the integration time of the sensor (the lens opening often remaining constant) 'on-the-fly' by evaluating either the average current from the image sensor, or looking at a dissected, sub-sampled group of images from the main sensor. This is similar to the SLR (single lens reflex) system described (A consumer digital camera using the sensor and multi-zone scene classification is the Nikon Coolpix 900).

Since an entire frame must be read, digitized, dissected and analyzed, and since auto-focus typically cannot be performed in parallel with AE calculations, this system has a potentially long *shutter press latency*. To reduce the shutter latency, the AE system may be kept running, so that AE calculations and adjustments are made continuously. Camcorders that record images continuously employ this system, exposure being calculated from the previously recorded frame or frames. A disadvantage of this implementation is the additional power demand of the CCD, analog front end and image processing microprocessor. For example, in capture mode, the Nikon Coolpix 900 continuously adjusts exposure and focus, which significantly reduces *shutter press latency* but also increases power consumption which in turn leads to reduced battery lifetime.

7. IMPACT OF VIEWFINDER FOR AE CONTROL

One aspect of digital camera that differs from its film counterpart is the addition of an image display – an on-board LCD. The LCD has two image viewing modes: *preview* and *review*. Many digital cameras incorporate a “traditional” optical viewfinder and a LCD with preview capability. The before mentioned Kodak DC260 and Nikon CoolPix 900 are two such examples. Other digital cameras rely on the LCD only and eliminating the optical viewfinder. The Agfa 1680 is one such example. Beside battery life consideration (LCD viewfinder consumes power continuously), there are also implications to the AE controls used for the camera.

Like conventional film cameras, an AE method that relies on mechanical shutter/iris for exposure control is compatible with optical viewfinder system. If an on-board LCD were to be used in viewfinder mode, the normally closed shutter/iris assembly must be held open to allow light through the lens during real time image display. The camera must then rely on adjusting the sensor integration time and the signal gain in the image processing chain to adjust exposure continuously.

Like conventional camcorders, digital cameras that use only the LCD as the viewfinder cannot rely on mechanical through-the-lens methods of controlling exposure level. Therefore, by the addition of a LCD with preview capability, the camera design must include electronic means of adjusting exposure level.

8. CONCLUSIONS

Auto-exposure is a very crucial component in the image-processing pipeline in a digital camera. AE implementation impacts the design of viewfinder and power consumption of the overall system. Table 3 enumerates the strengths and weaknesses of optics-centric and electronics-centric AE systems in digital cameras. Camcorders currently implement AE, auto-focus and white balance by way of application specific microprocessors.

Auto exposure system parameter	Electronics-centric	Optics-centric
AE speed	Because main sensor and imaging chain is employed, may be slow	Simple light metering circuitry provides fast response
AE accuracy	More information from scene is obtained, resulting in potentially more accurate exposures	Reflected light metering not optimal in 'difficult' lighting
Power consumption	Entire image chain used in AE calculation, potentially higher power demand	Simple light metering circuitry requires little power
Viewfinder	Works well in this system	Issue with mechanical shutter
AE versatility	Scene classification allows greater exposure compensation capability for difficult lighting	
Parts count	Components required for the image capture is also used for AE reducing parts count.	Separate sensor and A/D required increasing parts count. These components may be leveraged from existing high volume film cameras.

Table 3: Comparison of AE systems in digital cameras

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