A Review on Image Processing Sensor

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Abstract. Image sensors are used in all digital cameras, mobile phones and all other devices where images are to be captured. The most common parameter used by consumers to compare the different cameras is the pixel array size which is usually given in Mega pixels. The image quality is better with a higher megapixel count. Another parameter to distinguish between the different cameras is the type of imaging technology used like CMOS (Complementary metal oxide semiconductor) or CCD (Charge coupled devices). In this review we will present the working principles of an image sensor and conversion of light to electrical signals and subsequently to an image. The functional differences between the CCD and CMOS sensors will also be presented.

Keywords: CMOS (Complementary Metal Oxide Semiconductor), CCD (Charge Coupled Device), sensor, pixels, signal, charge, voltage.

1. Introduction

Nowadays sensors are used everywhere like in agriculture, entrances, even use for mosquito repellent and as a animal repellent [1-4]. A sensor converts one physical parameter into another physical parameter typically an electrical signal. Fig. 1 shows a generalized sensor block diagram.
An image sensor converts light signal or photons into electrical signal. The two main types are:
- The analog CCD sensor which converts photons to electrons
- The digital CMOS image sensor (CIS) which converts photon intensity to voltage [5-8]

1.1. CCD Image Sensor

CCD (Charge Coupled Device) is an image sensor with very high sensitivity. The CCD is composed of individual MOS diodes which are arranged in rows and columns. Each of this MOS diode is called a pixel. When a photon falls on the pixel electrons are generated in the individual device [5-8]. The generation of electrons is directly proportional to the intensity at each pixel. The amount of electrons is measured and the image is reconstructed. The CCD is clocked out to measure the electrons in each pixel and to form the image. As photons keeps falling on the pixel the number of electrons generated also keeps increasing eventually saturating the electrode. To avoid this the light must be blocked from falling on the CCD. An actual CCD contains a large of number of pixels, arranged in columns and rows. The size of the CCD is given by the number of rows and columns. The resolution of the CCD is defined by the pixel size, and also by the separation between pixels [9]. Charge Coupled Devices are of different types depending on the application or design. Fig. 2 shows the typical CCD pixel arrangement.

1.2. CMOS Image Sensor

Similar to CCD, a CMOS image sensor converts light into electrical signals while comparing to CCD it have advantage of high speed signal readout and low power consumption. CMOS image sensor circuits can be designed to fit onto a single chip, they are used primarily for small sized, low cost products, e.g., mobile phones and toy cameras. In CMOS image sensor, the pixel consists of a photodiode and a CMOS transistor as a switch [10]. Fig. 3 shows the sensor block diagram.
2. Literature review:

Willard Boyle and George E. Smith from Bell laboratories, developed a device called the Charge Bubbled Device while working on semiconductor-bubble-memory. This device can also be used as a Shift Register. This device can transfer charge from one pixel to the next [9]. Metal oxide semiconductors was used as a imaging device in the late 1960’s. Light was focused on to a 2D silicon array using a lens. The device captured the photons falling on the array and electrons are generated. These electrons are then transferred to a different location where the image is reconstructed. This device replaced the earlier vacuum tubes which were bulky and cumbersome. However, initially the MOS process were quite inconsistent which was not useful for imaging [10]. Presently two types are used in image sensors, namely CCD and CMOS.

Comparisons’ Between CCD and CMOS:

CCD sensors have very low noise and produce very high-quality images, while CMOS sensors have high noise and hence the quality is also low. CMOS sensors need better lighting to obtain a low noise image. However, nowadays the CMOS sensor technology is improving and it can match with the CCD sensor in resolution and overall quality. CMOS sensors have very low power consumption in comparison to CCD sensors. System complexity is high in CCD when compared to CMOS. In terms of sensor complexity is low in CCD and high in CMOS. When compared to COMS high dynamic range was observed in CCD and other hand tends to moderate level. And the range of shuttering in both the sensors was observed very fast, efficient. The image artifact in CCD includes smearing and charge transfer inefficiency, FPN (Fixed Pattern Noise) and PLS (Proximity Laser Scanner) are demonstrated in CMOS. High sensor complexity can be observed in CMOS when compared CCD, but whereas, system complexity is observed more in CCD when compared CMOS. Research and development cost high for CMOS when compared to CCD [4-8].

3. Methodology

The image sensor in a camera system gets photons that are focused on a using lens or else optics. Based on the type of sensor like CMOS or CCD, the information will be transmitted to the further stages like voltage or digital signal.

3.1. CCD Sensor Working

The CCD sensor technology uses the MOS capacitance. The photon falling on the device is absorbed in the depletion region and creates an electron-hole pair. The holes are attracted towards the electrode. Fig. 4 shows the cross-sectional image of a MOS gate. The CCD sensors can function from infrared to X-rays.

![MOS gate for P doped Silicon](image.png)
The image is focused on the capacitor array using a lens. Each capacitor in the array captures the photons and an equivalent electric charge is generated which is relative to the amount of the light photons. After the exposure of the array another control circuit moves the charge to the neighboring capacitor. The last capacitor in the array moves the charge to an amplifier which converts it to a voltage. Repetitively the control circuit transfers the entire charge in the array to make a voltage signal. This signal is fed further to other circuits for processing, recording or transmission.

Fig 5. Generalized CCD Block diagram

3.2. Charge generation

The device is biased before exposing to light. On biasing the holes are placed deep in the substrate with no electrons on the surface. After the exposure to light the electron-hole pairs are created in the depletion region. The biasing creates electric field which moves the electrons to the surface and the holes to the substrate. In all four process is involved, namely, Photo generation, depletion region generation, surface generation and neutral bulk generation. The last three generation process is called as dark-current generation and is the source of noise in the image.

Design and Manufacturing:
An epitaxial layer of silicon forms the photoactive region of CCD. This layer is mildly p-doped and fabricated on a substrate which is heavily p-doped. The gate is grown on the epitaxial layer. This layer forms the dielectric capacitor. Perpendicular channels of poly-silicon gates are deposited on top of this using chemical vapor deposition and patterned by photolithography. A channel stop is also grown to isolate the perpendicular channels and the charge packets in the columns.

Fig 6.CCD Technology

3.3. Architecture:

Various architectures are implemented for the CCD sensors. The common ones are full-frame, frame transfer and interline. In the full-frame the entire image area is active and it requires a mechanical shutter for readout. In the frame transfer part of the device area is made opaque so that the when the
device is clocked the image can be moved from the active region to dense region. Then the image can be slowly readout. These do not have a mechanical shutter. This type of architecture requires more silicon area and hence is also more costly compared to the full-frame. In the interline architecture every other column is masked for storage. Thus in one pixel shift the entire image is moved from the active area to storage area.

Types of CCDs:
- Frontside illuminated CCDs
- Backside illuminated CCDs

3.4. Front side illuminated CCDs:

Front side illuminated CCDs use the conventional wafer fabrication methods and are cheap mostly used in consumer electronics applications. This type of CCDs has low quantum efficiency.

Disadvantages:
- Low quantum efficiency
- Anti-reflection is not possible
- Response is poor

3.5. Backside illuminated CCDs

This type of CCDs are made by chemically etching and polishing the silicon and bringing the thickness down to 15 microns. The quantum efficiency is 100%. The thinning process is very specialized and very expensive. This is used in very high end applications.

Advantages:
- High quantum efficiency and quality image
- Very low noise and low dark current

Disadvantages:
- Non programmable
- Power consumption is high
3.6. Complementary Metal Oxide Semiconductor (CMOS):

The light is concentrated on the photosensitive area of the pixel using micro lenses. The photon is absorbed generating the electrons in the semiconductor area. Each pixel in the sensor is a photodiode which is further sequentially connected to three transistors. These transistors perform the function of activation, amplification and multiplexing. This makes the CMOS sensor to be high speed, but it has low sensitivity and high noise.

The two types CMOS detectors are Passive pixel and Active pixel. 
Passive pixel sensor (PPS):
Fig 10 shows the circuit diagram for a passive pixel sensor.

Advantage:  
- Higher fill factor

Limitations:  
- High noise  
- Slow read out  
- Lack of scalability

Active pixel sensor:  
Fig 11 shows the image of an active pixel sensor.
Advantages:
- High sensitivity
- High fill factor
- High readout speed
- Low power consumption and low cost
- Large array sizes

Applications:
- All type of consumer electronic devices where imaging sensor are used.
- Automobiles
- Wireless hand held devices
- Security cameras

4. Result

The information which was presented above gives the basic description of image sensors and its types and the comparison of image sensors with their functionality and architecture based on the user requirements. Image conversion from photons to electrical signal is achieved through the sensors. Different type’s image sensors are used in the process of manufacturing of different digital cameras. Usage of image sensors is not only limited to cameras but also extended to the medical applications, providing the security, and many other fields.

5. Conclusion

Here in this paper we have presented the different types of imaging sensors. The main type of imaging sensors used today are CCD and CMOS sensors. There are specific advantages and disadvantages of each type of sensor [11-15]. Depending on the application and other factors one can choose the right kind of sensor for their usage. The different sensors have been discussed and compared. If the user’s necessities are passable about certain circumstances such as low power consumption and money then go for CMOS. For better image enhancement go for CCDs. Based on various researches in future may expect that CMOS will match with CCDs in terms of image quality.

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