Problem 1.

1. (10%) Describe the basic principle of CCD and CMOS image sensors and list at least three of their differences

Ans part a(basic principles):

The basic principle of a CMOS image sensor

Ans part b(differences): keywords: analog, power, expense, quality, speed, noise

The biggest difference is the nature of the two devices. Although both a CCD and a CMOS convert light(photons) into voltage, they do so in very different ways, a CCD is an **analog** device while CMOS is digital. This immediately dictates that a CCD will need to include an external A/D function as part of the overall sensor. There are immediately several consequences of including an external A/D, the CCD sensor will require **more power,** and as a result will be more **expensive.**  However, because of the nature of the devices, analog vs digital and the use of a A/D, the CCD will have in general more dynamic range, sensitivity, and better **quality**. Finally, a CMOS sensor, where CMOS technology is very mature and forms the foundation of modern integrated circuits, will be **faster** due to the **switching speeds** of such digital electronics. Of course with the increase of speed, CMOS sensors have more **noise** than CCDs.

Problem 2.

1. (10%) List at least five types of camera sensor noises. Describe their origin, basic characteristics and how to fix them.

Ans:

1. **Photon Shot Noise**

This noise has its origins in the independence of photons and how they arrive at detectors. The number of photons arriving during a fixed time(exposure), is governed by Poisson’s probability distribution. The basic characteristic of the noise reflected in Poisson’s distribution is that given the average of the distribution you can predict statistically whether you will get k more events.

Fortunately the SNR for this type of noise is proportional to the square root of the average number of photons arriving at the detector. With an annealing effect from the proportional square root function, increasing the detector size, pixel area by a factor of 4x will increase the SNR by a factor of 2.

1. **Dark Current Noise**

Dark current noise is a low-level physics effect due to random behavior of holes and electrons in semiconductor material. As such, it increases linearly with exposure time and exponentially with temperature. Of course, because it is related to the actual material of the device it will vary across sensors that use different semiconductor material that has different doping characteristics

The most direct way to treat this type of noise is to cool the sensor with either water conduction or air flow convection. As noted above, just dealing with the exposure time is not enough as this is a linear relationship, and the temperature is exponential.

1. **Hot Pixels**

Hot pixel noise is primarily an electrical leaking phenomenon due to manufacturing defects. It is the leakage of electrical charge into the microscopic wells of the sensor that in the assignment of electrical charge the voltages are higher than they are (proportionality to photons) that they appear brighter by error.

From the literature it seems that hot pixels appear in all detectors and are hard to deal with as they change over time. Also, they are not only related to increases in exposure time, but to increases in temperature as well, where they are hard to model. Those that are related to temperature can be dealt with in the same way that dark current noise was addressed, with cooling. However, if this does not correct the problem and the hot pixel is repeatable, then perhaps the pixel can be removed in post digital signal processing of the image. Finally, if cooling or post-processing does not work, the exposure time can be experimented with to ameliorate the effects of hot pixels.

1. **Fixed Noise Pattern**

Fixed noise patterns are the result of manufacturing variations pixel columns in CMOS sensors and give some pixels a higher value than the background noise.

Since these types of noise do not change with time, they can be read once and subtracted for all other exposures.

1. **Read Noise**

The read noise mainly affects CMOS sensors and that is because of the nature of how A/D is done with CMOS. As opposed to CCD sensors, CMOS sensors have an A/D at each pixel and as a result affect directly the ability of an individual pixel to determine changes in amplitude for small signal changes. The analogy in digital electronics and digital signal processing would be the quantization level of the system as this determines the performance of a system to provide details to small changes.

Since this type of noise has some relationship to thermal noise then cooling is a possible alleviation.