restore satellite images distorted by mechanical jitter on a spacecraft; sharpen an image to bring out details; compressing images in a way so they still look good; for special effect sin movies, etc

5. These questions will need to be considered: How much compression do we need? What quality of image do we need? How will we measure that quality? What visual information is important for this application? Do we need to be able to recreate the image exactly, or will an approximation do?

6. Image restoration requires knowledge of the degradation process and uses a model to reverse the distortion. Image enhancement takes advantage of the human visual system's response and creates an image looks better, so does not model the "distortion".

Solutions for Chapter 2: Computer Imaging Systems

1. hardware and software.

2. Gigabyte Ethernet, Firewire, USB 3.0, Camera Link.

3. It samples an analog video signal to create a digital image. This sampling is done at a fixed rate when it measures the voltage of the signal and uses this value for the pixel brightness. It uses the horizontal synch pulse to control timing for one line of video (one row in the digital image), and the vertical synch pulse to tell the end of a field or frame

4. A sensor is a measuring device that responds to various parts of the EM spectrum, or other signal that we desire to measure. To create images the measurements are taken across a two-dimensional gird, thus creating a digital image.

5. A range image is an image where the pixel values correspond to the distance from the imaging sensor. They are typically created with radar, ultrasound or lasers.

6. The reflectance function describes the way an object reflects incident light. This relates to what we call color and texture it determines how the object looks.

7. Radiance is the light energy reflected from, or emitted by, an object; whereas irradiance is the incident light falling on a surface. So radiance is measured in Power/(Area)(SolidAngle), and irradiance is measure in Power./Area.

8. A photon is a massless particle that is used to model EM radiation. A CCD is a charge-coupled device. Quantum efficiency is a measure of how effectively a sensing element converts photonic energy into electrical energy, and is given by the ratio of electrical output to photonic input.

9. See fig 2.2-5 and use the lens equation: $\frac{1}{a}+\frac{1}{b}=\frac{1}{f}$. If the object is at infinity:

$$\frac{1}{\infty}+\frac{1}{b}=\frac{1}{f}=0+\frac{1}{b}=\frac{1}{f};\therefore f=b$$

10.

$$\begin{aligned}
N &= \delta A\delta t\int b(\lambda)q(\lambda)d\lambda \\
&= 20(10x10^{-3})\int_{400}^{700} 600\lambda(0.95)d\lambda \\
&= 114\int_{400}^{700}\lambda d\lambda = 114\left[\frac{\lambda^2}{2}\right]_{400}^{700} = 114(165{,}000) = 1.881x10^{7}
\end{aligned}$$

13. With interlaced scanning, a frame in 1/30 of a second is a field rate of 1/60 of a second. Here we 240 lines per field and 640 pixels per line which gives (240)(640) = 153,600 pixels in 1/60 of a second. So the sampling rate must be:

$\dfrac{153{,}600\,pixels}{{}^{1}\!/_{60}\,\text{sec}} = 9.216x10^{6}$; or about 9 megahertz

12. Gamma rays have the most energy, radio waves have the least. For human life, more energy is more dangerous.

13. UV is used in fluorescence microscopy, and IR images are used in remote sensing, law enforcement and fire detection.

14. Acoustic imaging works by sending out pulses of sonic energy (sound) at various frequencies, and then measuring the reflected waves. The time it takes for the reflected signal to appear contains distance information, and the amount of energy reflected contains information about the object's density and material. The measured information is then used to create a two or three dimensional image. It is used in geological applications, for example oil and mineral exploration, typically use low frequency sounds (around hundreds of hertz). Ultrasonic, or high frequency sound, imaging is often used in manufacturing to detect defects and in medicine to "see" inside opaque objects such as a woman's womb to image a developing baby.

15. Electron microscopes can magnify much more than light microscopes, 1,000 compared to 200,000 times. It uses a focused beam of electrons instead of light energy to image the objects.

16. 1) structured lighting created with a laser and rotating mirrors, 2) time-of-flight using a transmitter and receiver and various types of signals.

17. An *optical image* is a collection of spatially distributed light energy. Optical images can be represented as video information in the form of analog electrical signals, and these are sampled to generate the digital image $I(r,c)$.

18. A "real" image is measured by a sensor, a computer image is generated by software often using a mathematical model.

19. Binary images are 1-bit per pixel (bpp), gray-scale typically 8 bpp, color typically 24 bpp, and multispectral images can be many more bpp. With fewer bpp, we have less information, but smaller files. Binary images contain only shape information, gray-scale images contain brightness information, and color images have brightness information typically in three spectral

bands. Multispectral images have more than 3 bands and typically include information outside of the human visual spectrum.

20. Often to decouple the brightness and the color information, which creates a more people-oriented way of describing colors. Hue/Saturation/Lightness (HSL) color transform allows us to describe colors in terms that we can more readily understand (see Figure 2.4-3). The *lightness* (also referred as *intensity* or *value*) is the brightness of the color, and the *hue* is what we normally think of as "color"; for example green, blue or orange. The *saturation* is a measure of how much white is in the color; for example, pink is red with more white, so it is less saturated than a pure red.

21. It means that two different colors in one part of the color space will not exhibit the same degree of perceptual difference as two colors in another part of the color space, even though they are the same "distance" apart (see Figure 2.4-7). L*u*v* and L*a*b* are examples of perceptually uniform color spaces.

22. Inverse spherical coordinate transform (SCT):

$$R = L\sin(AngleA)\cos(AngleB)$$
$$G = L\sin(AngleA)\sin(AngleB)$$
$$B = L\cos(AngleA)$$

Inverse cylindrical coordinate transform (CCT):

$$R = d\cos\theta$$
$$G = d\cos(\pi/2-\theta)$$
$$B = z$$

23. For color printing we use a subtractive color model, where we consider subtracting cyan, magenta or yellow (CMY) from white, such as printing on white paper illuminated by white light. The model for white light is that it consists of red, green and blue. The CMY conversion

from RGB is defined as follows (these equations assume that the RGB values are normalized to the range of 0 to 1):

$$C = 1 - R$$
$$M = 1 - G$$
$$Y = 1 - B$$

Cyan absorbs red light, magenta absorbs green and yellow absorbs blue. Thus, to print a normalized RGB triple that appears green, (0,1,0), we would use CMY (1,0,1). For this example the cyan will absorb the red light and the yellow absorbs the blue light, leaving only the green light to be reflected and seen. Also, to print black we print all three (CMY) inks, and all the components of white light, RGB, will be absorbed. In practice, this produces a poor looking black, so black ink is added to the printing process leading to a four-color printing system, called CMYK.

For example, if (R,G,B) = (100,50,200)

$$Cyan = 1 - R = 1 - 100/255 \approx 0.608$$

$$Magenta = 1 - G = 1 - 50/255 \approx 0.804$$

$$Yellow = 1 - B = 1 - 200/255 \approx 0.216$$

24. *Bitmap images* (also called raster images) can be represented by our image model, *I(r,c)*, where we have pixel data and the corresponding brightness values stored in some file format. *Vector images* refers to methods of representing lines, curves and shapes by storing only the key points and then using this information to create a bitmap image by a process called rendering.

25. 1) the number of rows (height), 2) the number of columns (width), 3) the number of bands, 4) the number of bits per pixel (bpp), and 5) the file type.

26. VIP (Visualization in Image Processing) format. Standard image file types were not used because they may not handle floating point, complex data, any size, multiple bands and a special

history data structure that allows the maintenance of a record of operations that have been performed on the image

27. Experiment with CVIPtools.

Supplementary Exercises:

1. a) $f - number = \frac{f}{D_{effective}}$. The focal length, *f*, is fixed. We can change the f-number by changing the effective diameter by varying the aperture. As the effective diameter goes up, the f-number goes down, and vice versa. b) The amount of light energy that is intercepted by the lens is propotional to the area on which the light energy falls. In this case, the area of the circle of the lens with diameter D: Area = $\pi r^2 = \pi(D/2)^2 = (\pi/4)D^2$. So, we can see that the area is inversely to the f-number squared = $\frac{1}{(f - number)^2} = \left(\frac{D_{effective}}{f}\right)^2$. Since the area is propotional to the light energy, or brightness, the image brightness is inversely proportional to the f-number squared.

b) ***Alternate explanation***: Measuring the brightness by measuring the number of electrons liberated, and using *K* as a constant to represent that we have a fixed time interval and a constant incident photon flux, we can say:

$$N = \delta A \delta t \int b(\lambda) q(\lambda) d\lambda = Brightness = \pi \left(\frac{D_{eff}}{2}\right)^2 K = \frac{K\pi}{4}(D_{eff})^2$$

$$\therefore (D_{eff})^2 = \frac{4(Brightness)}{K\pi}$$

Where we use the area of the circular lens with D_{eff} as the effective lens diameter. Now since the f-number is given by: $f-number=\dfrac{f}{D_{eff}}$ and $(f-number)^2=\dfrac{f^2}{(D_{eff})^2}$, putting these two equations together:

$$(f-number)^2=\frac{f^2K\pi}{(Brightness)4}\rightarrow Brightness=\frac{f^2K\pi}{4(f-number)^2}$$

2. See figure 2.2-6 and apply similar triangles:

$$\frac{c/2}{b'-b}=\frac{d/2}{b'}$$

$$c/2=\frac{(b'-b)\,d/2}{b'}$$

$$c=\frac{d}{b'}|b-b'|$$

3.

$$N=\delta A\delta t\int b(\lambda)q(\lambda)d\lambda$$
$$=1000(10)\int_{400}^{700}1/(5\lambda+8)^2(0.8)\lambda d\lambda$$
$$=8{,}000\int_{400}^{700}\lambda/(5\lambda+8)^2\,d\lambda=8{,}000\left[\frac{8}{25(5\lambda+8)}+\frac{1}{25}\ln|5\lambda+8|\right]_{400}^{700}\approx 178$$

4. See Figure 2.2.6. Blur circle = $=\dfrac{50}{10.05025126}|10.03344482-10.05025126|=0.0834$ mm

Therefore, image is clear since blur circles less than the resolution of device

5. 1/a + 1/b = 1/50, and, a + b = 200; therefore, a = b = 100

6. See Figure 2.4.9. a) 0 b) 255 c) (455 + 333) = 788. 788/(577 + 333) = 0.865934.

(0.865934) x 255 ≈ 221

7. See Figure 2.2.6. Blur circle = $= \frac{100}{10.033445} | 10.033445 - 10.025063 | = 0.0835$ mm

Therefore, image is slightly blurry since blur circles greater than the resolution of device