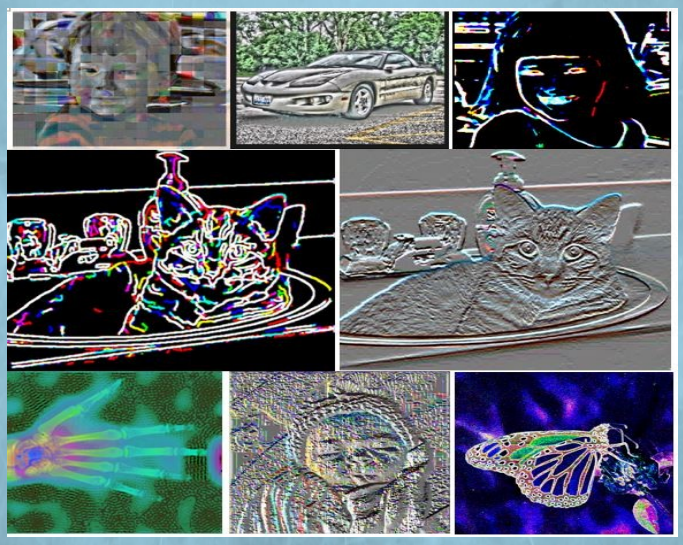
SOLUTIONS MANUAL

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Digital Image Processing and Analysis

COMPUTER VISION AND IMAGE ANALYSIS
Edition 4



SCOTT E UMBAUGH

Southern Illinois University Edwardsville

TABLE OF CONTENTS

SOLUTIONS FOR CHAPTER 1: DIGITAL IMAGE PROCESSING AND ANALYSIS....2
Supplementary Problems:....*7*
SOLUTIONS FOR CHAPTER 3: INTRODUCTION TO DIGITAL IMAGE ANALYSIS....9
Supplementary Problems....*14*
SOLUTIONS FOR CHAPTER 4: EDGE, LINE AND SHAPE DETECTION....18
Supplementary Problems....*22*
SOLUTIONS FOR CHAPTER 5: SEGEMENTATION....26
Supplementary Problems....*29*
SOLUTIONS FOR CHAPTER 6: FEATURE EXTRACTION AND ANALYSIS....31
Supplementary Problems....*35*
SOLUTIONS FOR CHAPTER 7: PATTERN CLASSIFICATION....40
Supplementary Problems....*42*
CVIPLAB WITH SAMPLE PROGRAMS AND SETUP FUNCTIONS....53
CVIPlab Header File....*72*
Threshold Function....*73*
Binary Features Function....*75*
Labeling Function....*77*
Euler Number Function....*81*
Complement Function....*83*
Logic Functions....*85*
Subtraction Function....*87*
Addition Function....*89*
Rotate Function....*91*
Convolution Mask (Filter) Function....*94*
Histogram Stretch/Shrink Function....*103*
Histogram Slide Function....*105*
Robert's Edge Detector Function....*108*
Sobel Edge Detector Function....*110*
Template Matching Function....*113*
CVIPlab with Sample CVIPtools Libraries Function Calls....*117*

Solutions for Chapter 1: Digital Image Processing and Analysis

1. *Digital image processing* is also referred to as *computer imaging* and can be defined as the acquisition and processing of visual information by computer. It can be divided into application areas of computer vision and human vision; where in computer vision applications the end user is a computer and in human vision applications the end user is a human. Image analysis ties these two primary application areas together, and can be defined as the examination of image data to solve a computer imaging problem. A computer vision system can be thought of as a deployed image analysis system.

2. In general, a computer vision system has an imaging device, such as a camera, and a computer running analysis software to perform a desired task. Such as: A system to inspect parts on an assembly line. A system to aid in the diagnosis of cancer via MRI images. A system to automatically navigate a vehicle across Martian terrain. A system to inspect welds in an automotive assembly factory.

3. The image analysis process requires the use of tools such as image segmentation, image transforms, feature extraction and pattern classification. *Image segmentation* is often one of the first steps in finding higher level objects from the raw image data. *Feature extraction* is the process of acquiring higher level image information, such as shape or color information, and may require the use of *image transforms* to find spatial frequency information. *Pattern classification* is the act of taking this higher level information and identifying objects within the image.

4. hardware and software.

5. Gigabyte Ethernet, USB 3.2, USB 4.0, Camera Link.

6. 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

7. 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.

8. 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.

9. 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.

10. 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.

11. 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.

12. See fig 1.4-5 and use the lens equation: $\frac{1}{a}+\frac{1}{b}=\frac{1}{f}$. If the object is at infinity:

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

13. Yes, solid state because the quantum efficiency is 95%

$$N = \delta A \delta t \int b(\lambda) q(\lambda) d\lambda$$

$$= 20\left(10 x 10^{-3}\right) \int_{400}^{700} 600\,\lambda(0.95)\, d\lambda$$

$$¿ 114 \int_{400}^{700} \lambda d\lambda = 114\left[\frac{\lambda^2}{2}\right]_{400}^{700} = 114(165,000) = 1.881 x 10^7$$

14. 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:

$$\frac{153,600\ pixels}{1/60\ \text{sec}} = 9.216 x 10^6$$; or about 9 megahertz

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

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

17. 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.

18. 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.

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

20. 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)*.

21. A “real” image is measured by a sensor, a computer image is generated by software often using a mathematical model.

22. 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.

23. 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.

24. 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.

25. 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):

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

26. *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.

27. 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.

28. 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

29. Experiment with CVIPtools.

Supplementary Problems:

1. See figure 1.4-6. and apply similar triangles:

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

2. 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: $f-number=\frac{f}{D_{eff}}$ and $(f-number)^2=\frac{f^2}{(D_{eff})^2}$, putting these two equations together:

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

3. a) $N=\delta A\delta t\int b(\lambda)q(\lambda)d\lambda$¿ $1000(10)\int_{400}^{700}\lambda$/¿¿¿ $8{,}000\int_{400}^{700}\lambda$/¿¿¿

b) Yes, it is solid state because the quantum efficiency is 0.8 or 80%

4. See Figure 1.4-6. Blur circle = $=\frac{50}{10.05025126}|10.03344482-10.05025126|$ = 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 1.5-10. a) 0 b) 255 c) (455 + 333) = 788. 788/(577 + 333) = 0.865934.

(0.865934) x 255 ≈ 221

7. See Figure 1.4-6. 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