Lab13: Image Processing

EECS20: Introduction to Real-Time Digital Systems

By K. H. Chiang, William T. Huang, Brian L. Evans.

URL: `http://www-inst.eecs.berkeley.edu/~ee20`
News: `ucb.class.ee20`

Assigned: 7 May 97, Checkoff: 14 May 97, Writeup Due: 16 May 97

1 Warning!

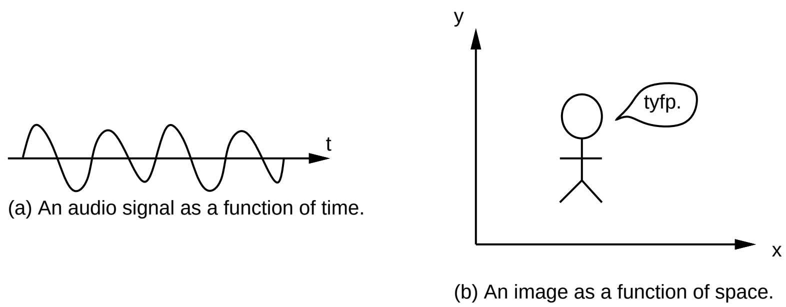
Resist printing this out from a web browser; you will get two huge images killing the printer. Print out the Postscript version instead.

2 Introduction

In previous labs, we worked with one-dimensional signals, which were good for representing sound. Extending the notion of a one-dimensional signal to two dimensions lets us deal with images.

3 The Frequency Domain

With audio, we could represent a signal as a sum of appropriately scaled and phase-shifted sinusoids. Since the audio signals were taken against time, as in Figure 1(a), "frequency" meant a variation in time.



(a) An audio signal as a function of time.

(b) An image as a function of space.

Figure 1: Signals as a function of time and space.

With images, we could also represent a signal as a sum of appropriately scaled and phase-shifted sinusoids. However, images are functions of *space*, as in Figure 1(b). So "frequency" means a spatial variation instead, and since we have two dimensions in space, we allow a spatial variation in the x direction and a spatial variation in the y direction.

4 Image Processing in Matlab

You will need to familiarize yourself with a number of commands in order to perform image processing in Matlab.

Station 1 is equipped with a camera that can be used to grab single frames. The capture program is in the Windows group "Video for Windows 1.1". Unfortunately, the only format that the capture program understands is `.dlb`. A conversion program should then be used to convert `.dlb` format to one of the following: `.bmp`, `.gif`, `.hdf`, `.pcx`, `.tiff`, or `.xwd`, since these formats are those that Matlab understands.

The following sequence of commands reads a file `khc.gif`, converts it to a grayscale image, and displays it with 256 gray levels. We will not be dealing with color images.

```
>> [I,map] = gifread('khc.gif');
>> J = ind2gray(I,map);
>> imshow(J,256)
>> colorbar
```

The first command reads the file into a matrix `I`. Each element of `I` represents a pixel in the image. The matrix `map` holds the colormap of the image; for GIFs, the colormap is usually 256 colors, where a color is a three element vector that represents some amount of three primary colors, usually red, green, or blue, but sometimes cyan, yellow, and magenta. Anyway, each pixel in `I` is an integer indexing into the colormap. Together, `I` and `map` are called an *indexed image*.

The second command converts the indexed image into a grayscale image; grayscale images are sometimes termed *intensity images*. The third command displays that image with 256 gray levels, while the final command adds a somewhat useful bar showing the gray levels to the right of the image.

In lab 6, we used the Matlab `fft` command to determine the frequency domain representation of a given signal. The `fft2` command extends `fft` to two-dimensional signals.

5 Filtering

As we saw with audio, we can filter a signal to recover its low frequency components. In one dimension, the ideal lowpass filter has a frequency response as in Figure 2(a). In two dimensions, the ideal LPF has a response as in Figure 2(b).

One of the more popular lowpass filters is the Gaussian, as in Figure 3, which has the interesting property that its frequency response is also a Gaussian. In Matlab, a Gaussian can be generated by using the `fspecial` command; assuming that we have a grayscale image `J`, the following commands will generate a Gaussian and filter `J` with that Gaussian:

```
>> g = fspecial('gaussian', n, sigma);
>> K = filter2(g, J);
>> imshow(K, 256);
```

The argument `n` sets the filter size; if `n` were 10, the resulting filter would be 10x10 in size. `sigma` sets the width of the Gaussian in pixels; the smaller the value, the higher the cutoff frequency.

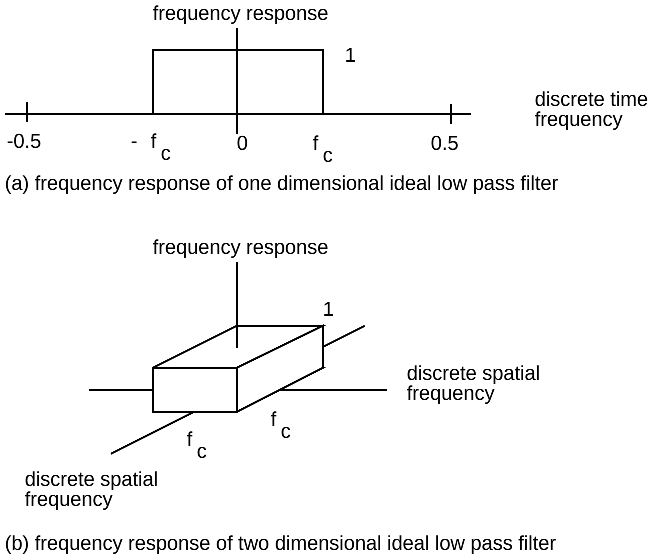


Figure 2: Ideal lowpass filter frequency responses.

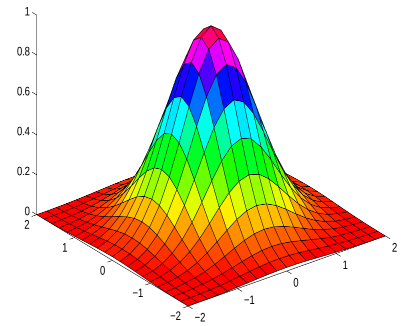


Figure 3: A token Gaussian.

6 Quantization

We saw that a one dimensional signal x could be quantized by normalizing and then performing:

```
>> floor(x*2^n) / 2^n
```

Two-dimensional signals can also be quantized. In the case of grayscale images, since the values all lie in the interval [0,1], normalization is unnecessary.

With audio, excessive quantization can be thought of as introducing signal-dependent noise. With images, excessive quantization introduces false contours and lines in the images.

7 Enhancement

In the medical community, image processing is useful in bringing out features in X-rays that would otherwise be obscured. Because different materials absorb X-rays at different rates, the intensity of a given pixel in the resulting grayscale image is indicative of the material at that spatial location.

Thus, certain features of given X-ray images can be enhanced by noting the range of intensities of the desired features, and then brightening the desired intensities, darkening the undesired ones, or some combination of both.

8 Compression

Sometimes we'd like to reduce the size of a given image, so that it takes up less storage space. This also allows us to consume less bandwidth when sending that image over a communications channel.

One of the more popular image storage formats is JPEG. JPEG employs the discrete cosine transform to perform lossy compression. The transform exhibits good energy compaction properties; energies that are largely evenly distributed in the signal domain usually end up in the lower frequency components in the frequency domain. This permits us to throw away the components corresponding to the higher frequencies, since they contain significantly less information, and the degradation in picture quality is not too noticeable.

Compression can also be performed by quantizing an image and then looking at the bit planes of that image. For instance, if an image is quantized to eight bits, there are eight bit planes, or eight black and white images. If the bit planes corresponding to the lower bits exhibit no structure [i.e. if they look like noise], then the entire bit plane can be thrown away with little degradation.

One more way compression can be performed is by plaids. If an image is treated as a matrix, a computationally expensive linear algebra technique called *singular value decomposition* can be done. If I is an M by N image, the SVD gives

$$I = U\Sigma V^*$$

Σ is a rectangular matrix of size M by N, with nonzero elements only on its main diagonal; let us suppose that these elements are arranged in decreasing order, and the after r of these elements, the rest are zero. The SVD gives U and V which are unitary, of size M by M and N by N respectively. If U is written in terms of its columns and V^* in terms of its rows, then:

$$\begin{aligned} I &= U\Sigma V^* \\ &= [u_1 u_2 \cdots u_N] \begin{bmatrix} \sigma_1 & & & & & \\ & \ddots & & & & \\ & & \sigma_r & & & \\ & & & 0 & & \\ & & & & \ddots & \\ & & & & & 0 \\ & & & & & \end{bmatrix} \begin{bmatrix} v_1^* \\ v_2^* \\ \vdots \\ v_M^* \end{bmatrix} \\ &= \sigma_1 u_1 v_1^* + \sigma_2 u_2 v_2^* + \cdots + \sigma_r u_r v_r^* \end{aligned}$$

Each of the r terms in the preceding sum are called plaids, since they resemble plaid cloth patterns. Anyway, not all r terms in the preceding sum are useful. After some point, the associated σ_i, where $0 \geq i \geq r$, are so small that they can be neglected. This is the basis of the plaid demonstration on the eecs20 web site.

9 Questions

1. Capture some images with the camera, and load them into Matlab.

2. Filter the images with a Gaussian. Experiment with different filter sizes and widths. What does filtering an image with a lowpass filter do to that image? Remember that "experiment" does *not* mean "use only one value and generalize from that single data point."

3. Construct a filter g_3 by subtracting a Gaussian filter g_1 of width σ_1 from a Gaussian filter g_2 of width σ_2, with $\sigma_2 < \sigma_1$ [so $g_3 = g_2 - g_1$]. Filter your images with the constructed filter g_3. Experiment with different values for σ_1 and σ_2. Is g_3 a lowpass, highpass, allpass, bandpass, or bandstop filter? Verify your answer by using the following Matlab command:

   ```
   >> surf(fftshift(abs(fft2(g3))));
   ```

4. Quantize some of the images you captured. How many bits are needed to adequately represent those images?

5. Enhance the bones of the spine in these medical images. [Hint: once you figure out what the range of intensities for the bone is, it's a one-liner in Matlab.] Store these images by right-clicking on them, and using the "save this image as..." option. Images courtesy of the National Center for Health Statistics, Centers for Disease Control (http://archive.nlm.nih.gov/nhanes/nhanes.html).

6. Run the discrete cosine transform demonstration:

   ```
   >> dctdemo
   ```

Now you have a feel for how JPEG works.

7. Compress an image by looking at its bit planes.

8. Compress an image by using plaids. Use the Matlab command `svd`:

```
>> [U,S,V] = svd(I);
```

Note that the `V` returned by Matlab is *not* V^*. Read the associated help text for the `svd` command for further details.