DSP Homework

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Abstract

1 Videos

1.1 History of Boston Dynamics

We can see in this video how the robots of Boston Power changed from the original ”noise maker” or ”two drunken people carrying the sofa” to various robots that play powerful functions according to their own characteristics.

At first, Boston Dynamics wanted to make a transport robot for the military that could be used in actual combat, but eventually stopped the project because of the excessive noise. Even though Boston Power once built such a robot again, it finally abandoned the original robot.

In turn, they began to make more refreshing kinds of bionic robots. For example, the smallest spot is developed with a flexible dog as its prototype; At the same time, there is also the humanoid robot Atlas, which is the most advanced product of Boston Power at present, promoting the technical innovation of software and hardware of the whole company.

1.2 Mosquitoes

Mosquitoes are a very disgusting kind of insects, one of the reasons is that they always keep buzzing in the summer. In this video, we can see that a researcher has captured many mosquitoes to study the ”melody” of their wings.

The researchers used a microphone to record the sound of mosquitoes flapping their wings and analyzed it with computer. They found that the frequency of male mosquitoes flapping their wings was not the same as that of female mosquitoes. But this is very obvious. Because there is a big difference in body size between male mosquitoes and female mosquitoes, female mosquitoes with large wings naturally can fly freely only by flapping their wings slowly.

The mosquito will take advantage of this difference when courting, that is, when mating, the mosquito will preferentially choose the opposite sex who can flap their wings with the same frequency.

1.3 Micro Robots

This video mainly introduces the Micro Robots in the title. Most of these robots use the appearance of insects and can move freely. They use their tiny body features to accomplish things that humans cannot do.

1.4 Our Planet

1.5 My Thoughts

History of Boston Dynamics

In the last ten years, Boston Power has achieved great success in bionic robots. There are not only assistant robots, but also commercially available robots like Stretch that are somewhat like worker bees. As the video finally said, robot people will ”occupy” the world, and robots will control power in science fiction, but in real life, It is really possible for robots to master the labor market one day.

Mosquitoes

Micro Robots

Our Planet

2 How fast do Mosquitoes Flap

2.1 Frequency Spectrum

First, draw the frequency spectrum, see Fig. 1 The fundamental frequency is about 400 Hz, if we want to know the

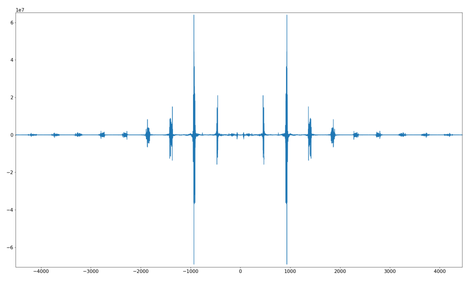


Figure 1: The Spectrum Of Mosquitoes Flipping Their Wings

instantaneous frequency mosquitoes flip, we only need the fundamental frequency, see Fig. 2.

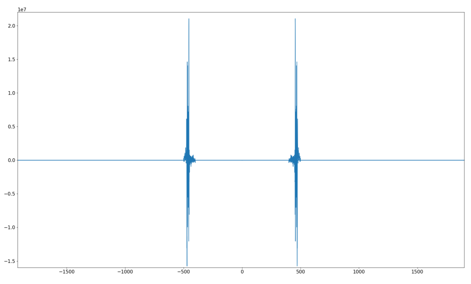


Figure 2: Base-band Spectrum of Mosquitoes’ Flipping

2.2 Counting With Schmidt Trigger

To know the instantaneous frequency, I want to cut the wave file into small slice, count how many times the line cross the zero point, and divide this count with the duration time of that small slice to get the frequency here. We usually use Schmidt trigger to this counting job, see Fig. 3.

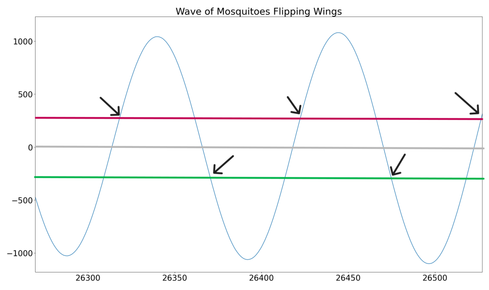


Figure 3: Schmidt Trigger Applied Here

2.3 Results

Here are my results, see Fig. 4.

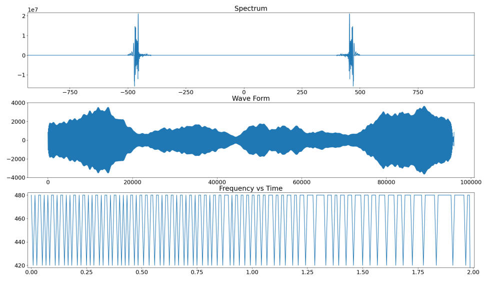


Figure 4: My Results

3 Base-band Wireless Communication Simulate

3.1 Simulation and Stability Analysis

I wrote my code by imitating your code, but I made some changes because I thought there might be a problem with the code in class. This mistake will explain the unstable behavior when noise (along with calculation error) is zero. I wrote my comparison in appendix.

In recovery process, we have

$$\begin{aligned} y &= x * h + n \\ \tilde{y} &= \tilde{x} \times \tilde{h} + N_0 \end{aligned} \tag{1}$$

So, the recovered signal $\hat{x}$ is as below

$$\begin{aligned} \mathcal{F}\{\hat{x}\} &= \tilde{y} \times \frac{1}{\tilde{h}} \\ &= (\tilde{x} \times \tilde{h} + N_0) \times \frac{1}{\tilde{h}} \\ &= \tilde{x} + \frac{N_0}{\tilde{h}} \end{aligned} \tag{2}$$

Here in (2), the IIR $N_0/\tilde{h}$, is why $\hat{x}$ can be unstable.

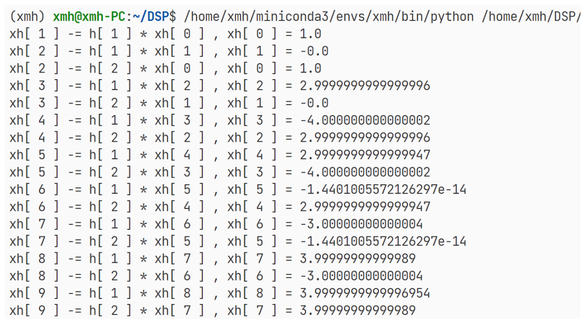
3.2 Unstable Behavior When Noise is Zero

In mathematics, it is impossible to see unstable behavior in (3).

$$\begin{aligned}\mathcal{F}\{\hat{x}\} &= \tilde{y} \times \frac{1}{\tilde{h}} \\ &= (\tilde{x} \times \tilde{h}) \times \frac{1}{\tilde{h}} \\ &= \tilde{x}\end{aligned} \tag{3}$$

So, there must be other noise in the code. What I found is that there will be a very small error in division of python, and it is exactly this little error that makes $1/\tilde{h}$ to oscillate infinitely.

Please see the terminal output in Fig. 5 which proves my guess.

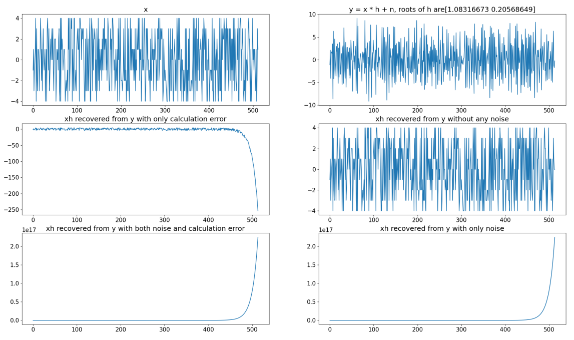


```
(xmh) xmh@xmh-PC:~/DSP$ /home/xmh/miniconda3/envs/xmh/bin/python /home/xmh/DSP/
xh[ 1 ] -= h[ 1 ] * xh[ 0 ] , xh[ 0 ] = 1.0
xh[ 2 ] -= h[ 1 ] * xh[ 1 ] , xh[ 1 ] = -0.0
xh[ 2 ] -= h[ 2 ] * xh[ 0 ] , xh[ 0 ] = 1.0
xh[ 3 ] -= h[ 1 ] * xh[ 2 ] , xh[ 2 ] = 2.9999999999999996
xh[ 3 ] -= h[ 2 ] * xh[ 1 ] , xh[ 1 ] = -0.0
xh[ 4 ] -= h[ 1 ] * xh[ 3 ] , xh[ 3 ] = -4.000000000000002
xh[ 4 ] -= h[ 2 ] * xh[ 2 ] , xh[ 2 ] = 2.9999999999999996
xh[ 5 ] -= h[ 1 ] * xh[ 4 ] , xh[ 4 ] = 2.9999999999999947
xh[ 5 ] -= h[ 2 ] * xh[ 3 ] , xh[ 3 ] = -4.000000000000002
xh[ 6 ] -= h[ 1 ] * xh[ 5 ] , xh[ 5 ] = -1.4401005572126297e-14
xh[ 6 ] -= h[ 2 ] * xh[ 4 ] , xh[ 4 ] = 2.9999999999999947
xh[ 7 ] -= h[ 1 ] * xh[ 6 ] , xh[ 6 ] = -3.00000000000004
xh[ 7 ] -= h[ 2 ] * xh[ 5 ] , xh[ 5 ] = -1.4401005572126297e-14
xh[ 8 ] -= h[ 1 ] * xh[ 7 ] , xh[ 7 ] = 3.99999999999989
xh[ 8 ] -= h[ 2 ] * xh[ 6 ] , xh[ 6 ] = -3.00000000000004
xh[ 9 ] -= h[ 1 ] * xh[ 8 ] , xh[ 8 ] = 3.9999999999996954
xh[ 9 ] -= h[ 2 ] * xh[ 7 ] , xh[ 7 ] = 3.99999999999989
```

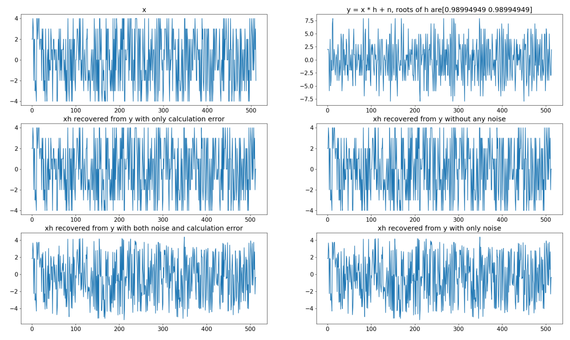
Figure 5: Error in Division Calculation

This error is revealed in float numbers like $2.99\cdots96$ and $-4.00\cdots02$ in line 4 and 6 of Fig. 5.

There are my comparison between whether there is noise or calculation error in signal y, see Fig. 6.



(a) $\tilde{h}$ is stable



(b) $\tilde{h}$ is unstable

Figure 6: Stability Comparison when $\tilde{h}$ is different

We can see in Fig. 6(a) that when $\tilde{h}$ is unstable, $\hat{x}$ recovered from y only with calculation error went infinite, but y without both calculation error and noise can be perfectly recovered. This phenomenon is because unstable amplified the noise or the calculation error in recovery, so if there's no disturb in y, it is possible to recover the original signal x.

Also, when $\tilde{h}$ is stable or is decrement oscillation, the noise and the calculation error will be decreasing along with the recovery process, so without noise is no longer a necessary condition for signal recovery. However, in this condition, only y without any noise can be perfectly recovered ($\hat{x} = x$).

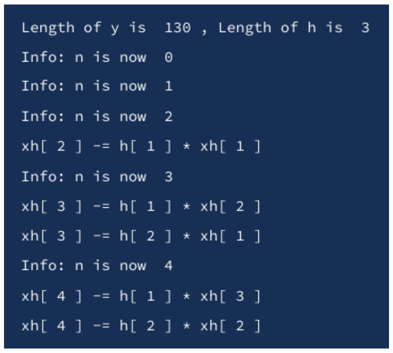
Appendix A Possible Mistakes in Lesson

Dear Yi, I may found a small mistake in your code on Tuesday's (Dec.6) lesson. It is about the recovering of from $y = x * h$.

Please see the probably incorrect code as below:

```
def reX_estimate(y, h):
  N = len(y)
  M = len(h)
  print("Length of y is ", N,", Length of h is ", M)
  xh = y.copy()
  for n in range(N):
    print("Info: n is now ", n)
    for m in range(1, min(M, n)): # Mistake here, n should be n + 1
      xh[n] -= h[m] * xh[n - m]
      print("xh[", n,"] -= h[",m,"] * xh[",n - m,"]")
    xh[n] /= h[0]
  return xh
```

The length of h is 3 and the roots of h are about $[1.77, 0.57]$. Key point is in the output, see Fig. 7.



```
Length of y is  130 , Length of h is  3
Info: n is now  0
Info: n is now  1
Info: n is now  2
xh[ 2 ] -= h[ 1 ] * xh[ 1 ]
Info: n is now  3
xh[ 3 ] -= h[ 1 ] * xh[ 2 ]
xh[ 3 ] -= h[ 2 ] * xh[ 1 ]
Info: n is now  4
xh[ 4 ] -= h[ 1 ] * xh[ 3 ]
xh[ 4 ] -= h[ 2 ] * xh[ 2 ]
```

Figure 7: Output of Test Code

We can find that while $\hat{x}[2] = y[2] = h[0] \times x[2] + h[1] \times x[1] + h[2] \times x[0]$, this code only minus $h[1] \times x[1]$, that is the small mistake.

This small mistake in recovering x is *working as noise*, as a result, the $h(n)$ which is an unstable IIR, will *amplify this noise* and finally cause the *unstable behavior*. As the Fig. 8 revealed.

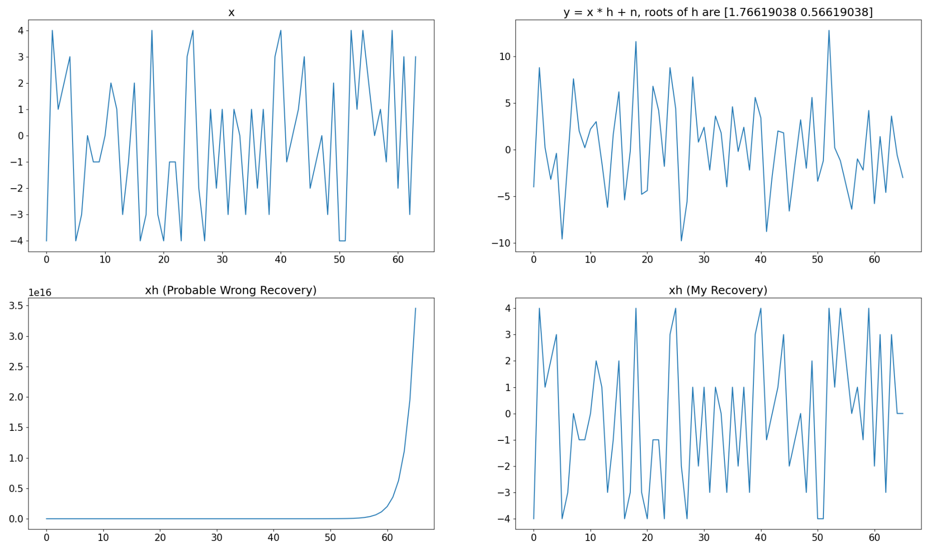


Figure 8: Different Behavior Between Previous Code and Current Code

Appendix B Code Listing

```
# simulate.py
import numpy as np
import matplotlib.pyplot as plt
```

```
plt.rcParams.update({'font.size': 15})

def genPAM(N, M):
    """Generate PAM Signal"""
    return (np.random.randint(-M, M + 1, (N)))

def genNoise(y, snr = 20):
    """Generate White Noise"""
    Es = np.mean(y**2)
    sigma = np.sqrt(Es / 10 ** ( snr / 10))
    n = sigma * np.random.randn(len(y))
    return n + y, n

def reX_estimate(y, h, ErrorFlag=1):
    """Estimate x From y"""
    N = len(y)
    M = len(h)
    xh = y.copy()
    for n in range(N):
        # print("Info: n is now ", n)
        for m in range(1, min(M, n + 1)):
            xh[n] -= h[m] * xh[n - m]
            # if ErrorFlag and n <= 20:
            #     print("xh[", n,"] -= h[",m,"] * xh[",n - m,"]", ", xh[", n - m,"] =",xh[n - m])
        xh[n] /= h[0]
        if ErrorFlag == 0:
            xh[n] = np.round(xh[n], 8) #Exclude Error generated by calculation accuracy
    return xh

#parameters
N = 256
Nc = 3
M = 4

#generate x and h randomly
x = genPAM(N, M)
h = np.random.randn(Nc)
# h = [1, 0, -0.98]

#generate y as received signal
y = np.convolve(x, h)
yn, n = genNoise(y, snr = 30)

#recover x in different methods
xh = reX_estimate(y, h)
xh_new = reX_estimate(y, h, ErrorFlag=0)
xhn = reX_estimate(yn, h)
xhn_new = reX_estimate(yn, h, ErrorFlag=0)

#draw the results and the comparison
fig = plt.figure(figsize=(12, 8))

ax = fig.add_subplot(3, 2, 1)
ax.plot(x)
ax.set_title('x')
ax = fig.add_subplot(3, 2, 2)
ax.set_title('y = x * h + n, roots of h are' + str(np.abs(np.roots(h))))
ax.plot(y)
ax = fig.add_subplot(3, 2, 3)
ax.set_title('xh recovered from y with only calculation error')
ax.plot(xh)
ax = fig.add_subplot(3, 2, 4)
ax.set_title('xh recovered from y without any noise')
ax.plot(xh_new)
ax = fig.add_subplot(3, 2, 5)
ax.set_title('xh recovered from y with both noise and calculation error')
ax.plot(xhn)
ax = fig.add_subplot(3, 2, 6)
ax.set_title('xh recovered from y with only noise')
ax.plot(xhn_new)

plt.show()
```

```
# Mosquito.py
```

```python
from scipy.io.wavfile import read, write
import numpy as np
from numpy.fft import fft, fftfreq, ifft
from matplotlib import pyplot as plt
plt.rcParams.update({'font.size': 18})

def loadWAV(fname):
    fs, w = read(fname)
    sec = len(w)/fs
    wt = fft(w)
    freq = fftfreq(wt.size, d=1/fs)
    """Simple High-Pass Filter"""
    fl = 400
    wt[int(-fl * sec):] = 0
    wt[:int(fl * sec)] = 0
    """Simple Low-Pass Filter"""
    fh = 500
    cfq = wt.size/2
    wt[int(cfq - (fs/2 - fh) * sec):int(cfq + (fs/2 - fh) * sec)] = 0
    return fs, w, wt, freq

def countFlip(w, fs, gate, intv):
    N = len(w)
    M = N//intv
    count = 0
    L = np.zeros(M)
    if w[0] > 0:
        flag = 1
    else:
        flag = -1
    for n in range(M):
        for m in range(intv):
            index = int(intv * n + m)
            if flag * w[index] > -gate:
                pass
            else:
                count += 1
                flag = w[index] / np.abs(w[index])
        L[n] = count/2
        count = 0
    return intv/fs, L

fs, w, wt, freq = loadWAV("/home/xmh/DSP/projF/code/mosquito-cut.wav")
iw = np.array(np.real(ifft(wt)), dtype=np.int16)
write('/home/xmh/DSP/projF/code/mosquito-out.wav', fs, iw)

dt, L = countFlip(iw, fs, gate=300, intv=400)
F = L/(dt)
gapTime = np.arange(0, 2, dt)

fig = plt.figure(figsize=(12, 8))

ax = fig.add_subplot(311)
ax.set_title("Spectrum")
ax.plot(freq, np.real(wt))

ax = fig.add_subplot(312)
ax.set_title("Wave Form")
ax.plot(iw)

ax = fig.add_subplot(313)
ax.set_title("Frequency vs Time")
ax.plot(gapTime, F)

plt.show()
```