

# DSP Assignment 2

## FIR Filter

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### **Declaration of Originality and Submission Information**

I affirm that this submission is my own / the groups original work in accordance with the University of Glasgow Regulations and the School of Engineering Requirements.

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# 1 ECG Filtering

## 1.1 Introduction

Fast Fourier Transform is a transformation which requires the full recording data to perform, so it is not suitable for real-time processing. As a result, the finite-impulse response filter or FIR filter which is a causal digital filter that only takes finite number of sample from the whole data to perform was implemented. However, note that FIR filter only do semi-real time processing because its implementation involves buffer which introduces time delay.

ECG signal measured is subjected to 50 Hz noise and DC line shift which needs to be removed. In cases that almost real time filtering is needed, such as filtering the ECG signal to display on a patient monitor, FIR filter is used instead of Fast Fourier Transform. However, the result from Fast Fourier Transform would actually be more accurate because it takes more sample to process.

FIR filter is written as a function that takes 1 data in and outputs 1 data at a time, so it is used for semi-real time processing. The process of an FIR filter is to sum up the multiplication of the coefficients of the filter and the corresponding data stored in buffer which will be shifted every time a new data is fed. Furthermore, we are using ring buffer to reduce computation resource from normally shifting the array operation.

## 1.2 Method and Results

The implementation of this part consists of 2 python files, `fir_filter.py` and `ecg_filter.py`. `fir_filter.py` contains the FIR filter class which needs coefficient array as the input. It will automatically runs the `unittest()` if it is run in the `main()` function. `ecg_filter.py` contains 2 filters made from the FIR filter class(from `fir_filter.py`) and imports raw ecg data to filter. It saves the results as `shortecg.dat`(from `ECG.dat`) and `shorteint.dat`(from `Einthoven.ii Walking`).

### 1.2.1 FIR-filter Function

```
20 import numpy as np
21 class FIR_filter:
22     def __init__(self, coefficients):
23         self.coeff = coefficients
24         self.offset = 0
25         self.buffer = np.zeros(len(coefficients))
```

Listing 1: Initialise Constructor

Import the libraries used by the code.

- **numpy** : array processing and mathematical calculations

The constructor of the class is initialised with the local variables inside the constructor function: **coeff**, **offset** and **buffer**. **coeff** consists of the input coefficients or the impulse response of the filter. It will be taken from the input

when you instantiate the filter class. **offset** is the position of the current data on the buffer of the processed data which is used only inside the filter class. Finally, **buffer** is created by having an array of zeros with the size of the coefficients number to store all delayed data.

```

27 def dofilter(self,u):
28     result = 0
29     self.buffer[self.offset] = u
30     #print("offset index:",self.offset)
31
32     for i in range(self.offset+1):
33         result = result + self.buffer[i]*self.coeff[self.offset
34         -i]
35         #print("buffer index:",i)
36         #print("coeff index:",self.offset-i)
37
38         #print("Second For Section")
39         for i in range(self.offset+1,len(self.buffer),1):
40             result = result + self.buffer[i]*self.coeff[len(self.
41             buffer)-1+self.offset+1-i]
42             #print("buffer index:",i)
43             #print("coeff index:",len(self.buffer)-1+self.offset+1-
44             i)
45
46         self.offset+=1
47         if self.offset>=len(self.buffer):
48             self.offset=0
49
50     return result

```

Listing 2: Ring Buffer Function

New input from the outside is put into the **offset** th position of the buffer. Note that the **offset** increments every time a new data was input. It then resets at the maximum size of the length of the buffer, which is the length of the coefficient. There are 2 **for-loop** to operate the multiplication process. The index of the coefficients and the buffer slots multiplied are shown in figure 1.

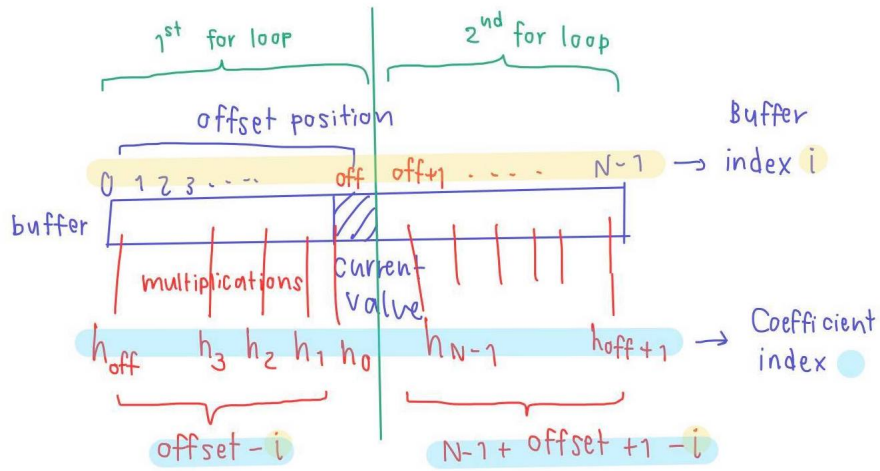


Figure 1: Ring Buffer Index Diagram

**dofilterPrint** is the exact same function as **dofilter**, but with the **print** lines uncommented. We use this **dofilterPrint** in **unittest()** only, so we can see which coefficient is being multiplied to which buffer. It also shows which pairs are being done on which **for-loop**.

```

49     def dofilterPrint(self,u):          #index printing version for
diagnosis purpose
50         result = 0
51         self.buffer[self.offset] = u
52         print("offset index:",self.offset)
53
54         for i in range(self.offset+1):
55             result = result + self.buffer[i]*self.coeff[self.offset
-i]
56             print("buffer index:",i)
57             print("coeff index:",self.offset-i)
58
59         print("Second For Section")
60         for i in range(self.offset+1,len(self.buffer),1):
61             result = result + self.buffer[i]*self.coeff[len(self.
buffer)-1+self.offset+1-i]
62             print("buffer index:",i)
63             print("coeff index:",len(self.buffer)-1+self.offset+1-i
)
64
65         self.offset+=1
66         if self.offset>=len(self.buffer):
67             self.offset=0
68
69         return result

```

Listing 3: dofilterPrint

`unittest()` is testing with coefficient  $[0.5, 0.5, 0, 0]$  and input  $[0, 1, 0, 0, \dots]$  (impulse). Because the solution is obvious  $[0, 0.5, 0.5, 0, 0, \dots]$ , it can be used to check primarily if the filter is functioning correctly. The `print` function from the `dofilterPrint` also helps checking the indices.

```

71 def unittest():
72     h = np.array([1/2, 1/2, 0, 0, 0])
73     print("Coefficient:", h)
74     f = FIR_filter(h)
75     y = f.dofilterPrint(0)           #use the index printing version
76     print("Input 0, Output", y)
77     y = f.dofilterPrint(1)           #use the index printing version
78     print("Input 1, Output", y)
79     for i in range(20):
80         y = f.dofilterPrint(0)       #use the index printing version
81         print("Input 0, Output", y)
82
83 if __name__ == "__main__":
84     unittest()

```

Listing 4: `unittest()`

### 1.2.2 ECGfilter.py

```

1 import numpy as np
2 from fir_filter import FIR_filter
3 from numpy import loadtxt
4 from matplotlib import pyplot
5
6 fs = 250      #Hz
7 M = 500      #loses 2 heart beat to warm up the filter (2seconds)

```

Listing 5: Import FIR\_Filter Class

To initialize the code, `fir_filter.py` must be located in the same folder, so it could be imported to the code. The sampling frequency is 250 Hz, and the length of the coefficient is 500 elements (number of taps/number of delay buffer). The number of coefficient should be high enough to make frequency resolution becomes enough for the 0.5 Hz frequency cutoff in our DC filter design. Frequency resolution in this case equals  $250 \text{ Hz} / 500 \text{ taps} = 0.5 \text{ Hz}$  which is exactly how good resolution we need. The trade off for high coefficient number is that it takes time for the buffer to fill up before it can actually function.

```

10 # 50 Hz Notch Filter
11 k1 = int(49.5/fs * M)
12 k2 = int(50.5/fs * M)
13
14 Window50 = np.ones(M)
15 Coeff50 = np.ones(M)
16
17 Window50[k1:k2+1] = 0
18 Window50[M-k2:M-k1+1] = 0
19

```

```

20 pyplot.figure(1)
21 pyplot.plot(Window50)
22 pyplot.title('50 Hz Notch Filter - Ideal')
23 pyplot.xlabel('M (sample number)')
24 pyplot.ylabel('Amplitude')
25 # pyplot.savefig('ecg_fig1.eps', format='eps')
26
27 W50 = np.fft.ifft(Window50)
28 W50 = np.real(W50)
29
30 pyplot.figure(2)
31 pyplot.plot(W50)
32 pyplot.title('50 Hz Notch Filter - IFFT')
33 pyplot.xlabel('Coefficient Index')
34 pyplot.ylabel('Amplitude')
35 # pyplot.savefig('ecg_fig2.eps', format='eps')
36
37 Coeff50[0:int(M/2)] = W50[int(M/2):M]
38 Coeff50[int(M/2):M] = W50[0:int(M/2)]
39
40 pyplot.figure(3)
41 pyplot.plot(Coeff50)
42 pyplot.title('50 Hz Notch Filter - IFFT(fixed)')
43 pyplot.xlabel('Coefficient Index')
44 pyplot.ylabel('Amplitude')
45 # pyplot.savefig('ecg_fig3.eps', format='eps')
46
47 Filter50 = FIR_filter(Coeff50)

```

Listing 6: 50 Hz Bandstop Coefficient

To create coefficient array for the 50 Hz removal, an ideal notch filter(sequence of 0s and 1s) is created with targeting of 49.5 Hz(**k1**) to 50.5 Hz(**k2**) for the cutoff frequencies. The inverse fast-fourier transform is applied to the ideal filter array, then array manipulation is applied to shift the coefficients by half of the length of the coefficient to swap the positions to make it causal and intact.

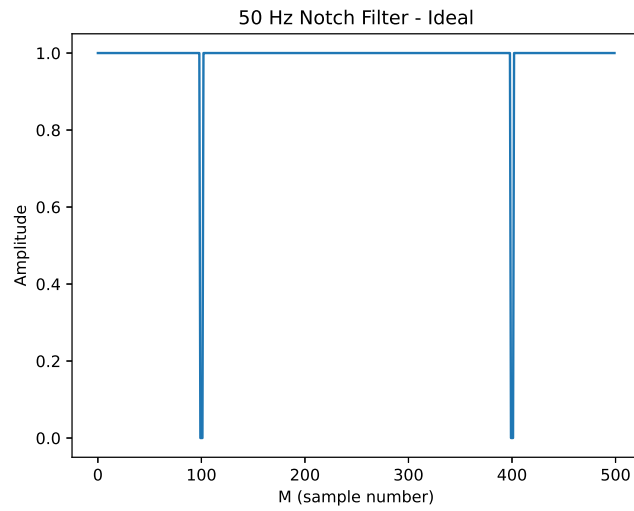


Figure 2: 50 Hz Notch Filter Ideal Frequency Domain Plot

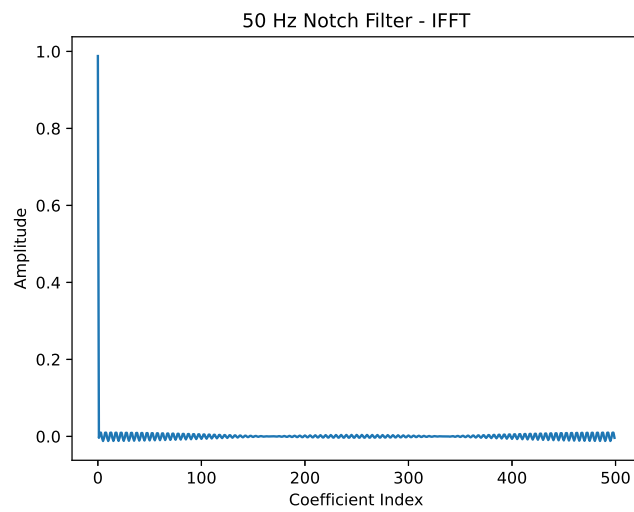


Figure 3: 50 Hz Notch Filter IFFT

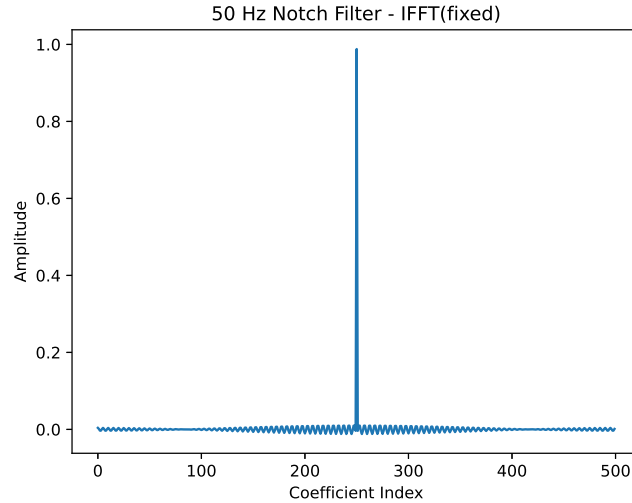


Figure 4: 50 Hz Notch Filter IFFT (fixed) - Coefficients

To remove the DC line shift from the data, a window function coefficient is created by targeting the 0.5 Hz as the cutoff frequency. The same procedure as the 50 Hz notch filter applies.

```

50 #DC filter
51 k3 = int(0.5/fs * M)
52 WindowDC = np.ones(M)
53 CoeffDC = np.ones(M)
54
55 WindowDC[0:k3+1] = 0
56 pyplot.figure(4)
57 pyplot.plot(WindowDC)
58 pyplot.title('DC Filter - Ideal')
59 pyplot.xlabel('M (sample number)')
60 pyplot.ylabel('Amplitude')
61 # pyplot.savefig('ecg_fig4.eps', format='eps')
62
63 WDC = np.fft.ifft(WindowDC)
64 WDC = np.real(WDC)
65
66 pyplot.figure(5)
67 pyplot.plot(WDC)
68 pyplot.title('DC Filter - IFFT')
69 pyplot.xlabel('Coefficient Index')
70 pyplot.ylabel('Amplitude')
71 # pyplot.savefig('ecg_fig5.eps', format='eps')
72
73 CoeffDC[0:int(M/2)] = WDC[int(M/2):M]
74 CoeffDC[int(M/2):M] = WDC[0:int(M/2)]
75
76 pyplot.figure(6)
77 pyplot.plot(CoeffDC)

```



```

78 pyplot.title('DC Filter - IFFT(fixed)')
79 pyplot.xlabel('Coefficient Index')
80 pyplot.ylabel('Amplitude')
81 # pyplot.savefig('ecg_fig6.eps', format='eps')
82
83 FilterDC = FIR_filter(CoeffDC)

```

Listing 7: DC Filter Coefficient

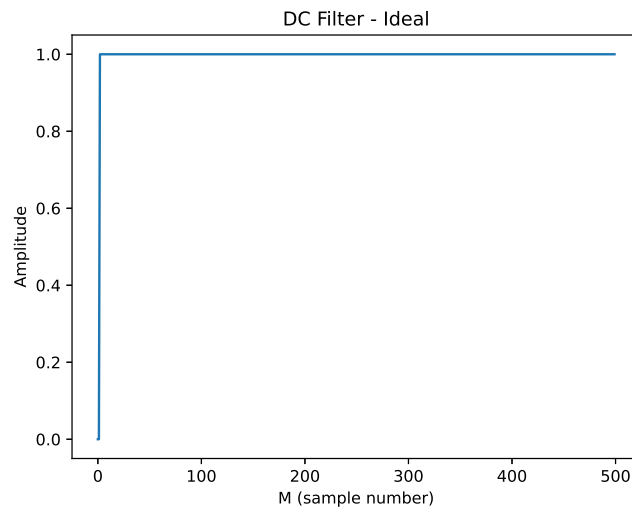


Figure 5: DC Removal Filter Ideal Frequency Domain Plot

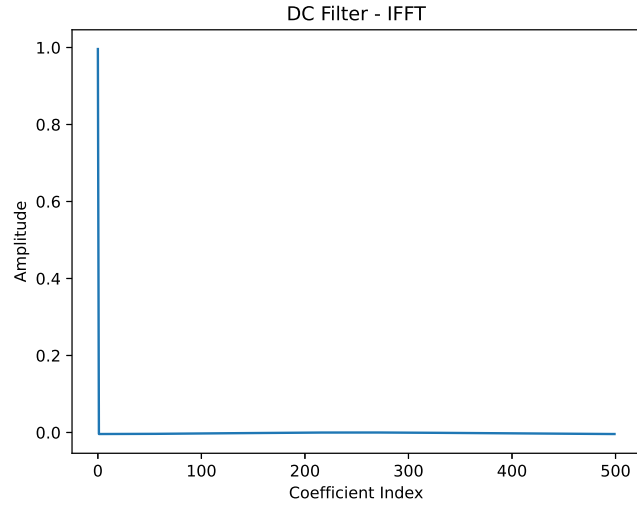


Figure 6: DC Removal Filter IFFT

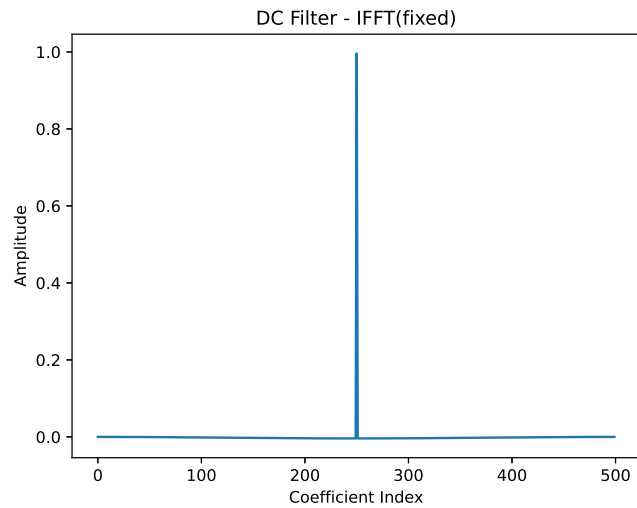


Figure 7: DC Removal Filter IFFT (fixed) - Coefficients

We load .dat ECG data to our file to perform semi-real time processing and plot them in time domain.

```

86 # load first ECG file
87 file1 = open('ECG.dat', 'r')    #line by line to use as real-time
    filter

```

```

88
89 ecg = loadtxt("ECG.dat")           #for diagnosis plot
90
91 pyplot.figure(7)
92 print(len(ecg))
93 time = np.linspace(0, len(ecg)/fs, len(ecg))
94 pyplot.plot(time, ecg)
95 pyplot.title('ecg (raw)')
96 pyplot.xlabel('Time(s)')
97 pyplot.ylabel('Amplitude')
98 #pyplot.savefig('ecg_fig7.eps', format='eps')
99
100
101 # Investigate frequency domain
102 fx=np.fft.fft(ecg)
103 fxx = fx/len(ecg)           # Fourier Transform Normalised
104 dbs = 20*np.log10(abs(fxx))  # DB Conversion
105 pyplot.figure(8)
106 freq = np.linspace(0, fs, len(ecg))
107 pyplot.plot(freq, dbs)
108 pyplot.title('ecg (raw) - Frequency Domain')
109 pyplot.xlabel('Frequency (Hz)')
110 pyplot.ylabel('Amplitude')
111 #pyplot.savefig('ecg_fig8.eps', format='eps')
112
113 #load second ECG data
114 '''Initialise experiments from the files of einthoven'''
115 subject_number = 3
116 experiment = 'walking'
117 ecg_class = GUDb(subject_number, experiment)
118
119 '''Initialise experiments from the files of einthoven'''
120 chest_strap_V2_V1 = ecg_class.cs_V2_V1
121 einthoven_ii = ecg_class.einthoven_II
122
123 '''Filtered Data With Einthoven'''
124 ecg_class.filter_data()
125 einthoven_ii_filt = ecg_class.einthoven_II_filt
126
127 #define output array and intermediate variable
128 filterecg = np.zeros(len(ecg)+1)
129 filtereinthoven = np.zeros(len(einthoven_ii)+1)
130 intermediate = 0
131
132
133
134
135
136
137 pyplot.figure(11)
138 #print(len(einthoven_ii))
139 time4 = np.linspace(0, len(einthoven_ii)/fs, len(einthoven_ii))
140 pyplot.plot(time4, einthoven_ii)
141 pyplot.title('einthoven_ii (raw)')
142 pyplot.xlabel('Time(s)')
143 pyplot.ylabel('Amplitude')
144 #pyplot.savefig('ecg_fig11.eps', format='eps')

```

Listing 8: Load .dat Files and Time Domain Plot

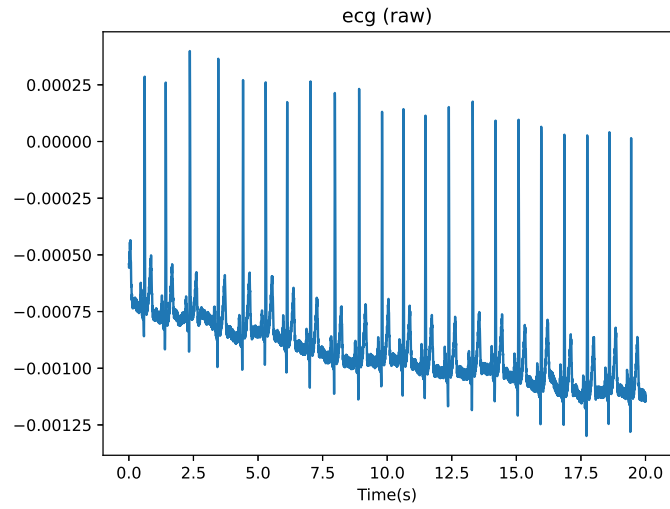


Figure 8: Raw ECG from ECG.dat

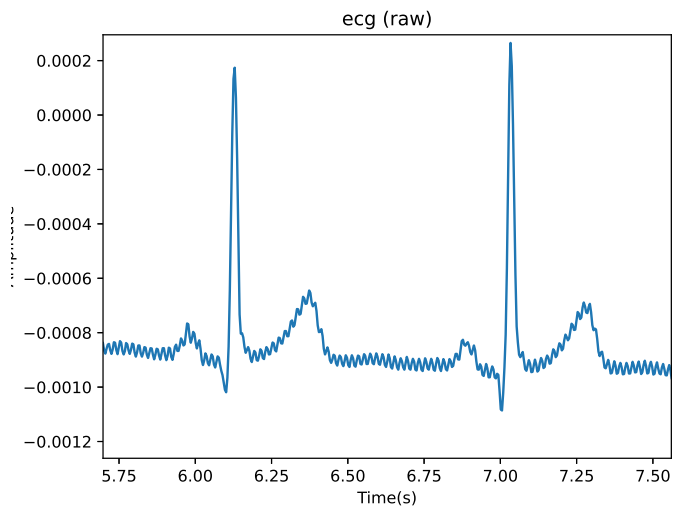


Figure 9: Partly Raw ECG from ECG.dat

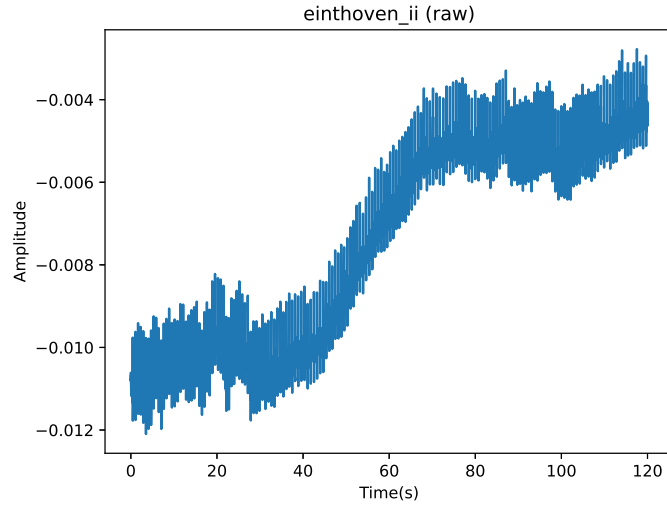


Figure 10: Raw ECG from Einthoven\_ii Walking

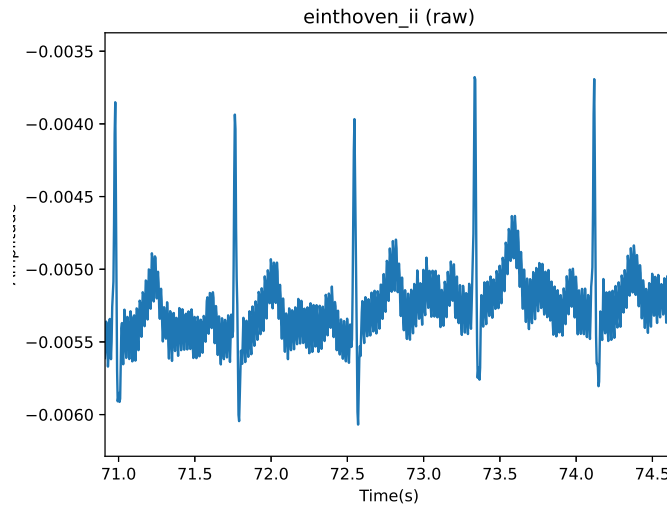


Figure 11: Partly Raw ECG from Einthoven\_ii Walking

We perform both 50 Hz notch filter and DC filter to both data sets and plot the filtered ECG.

```
132 #filter ecg for both data sets
133 count = 0
```

```

134 for line in file1:
135     count += 1
136     ecg1 = line.strip()
137     #print(ecg1)
138     intermediate = Filter50.dofilter(ecg1)
139     filterecg[count] = FilterDC.dofilter(intermediate)
140
141 for i in range(len(einthoven_ii)):
142     intermediate = Filter50.dofilter(einthoven_ii[i])
143     filtereinthoven[i] = FilterDC.dofilter(intermediate)
144
145 #print(count)
146
147 #plot the filtered data
148 pyplot.figure(9)
149 time2 = np.linspace(0, len(filterecg)/fs, len(filterecg))
150 pyplot.plot(time2, filterecg)
151 #pyplot.ylim(-0.002, 0.002)
152 pyplot.title('ecg (filtered)')
153 pyplot.xlabel('Time(s)')
154 pyplot.ylabel('Amplitude')
155 #pyplot.savefig('ecg_fig9.eps', format='eps')
156
157 pyplot.figure(10)
158 time3 = np.linspace(0, len(filtereinthoven)/fs, len(filtereinthoven))
159 pyplot.plot(time3, filtereinthoven)
160 pyplot.ylim(-0.002, 0.002)
161 pyplot.title('einthoven (filtered)')
162 pyplot.xlabel('Time(s)')
163 pyplot.ylabel('Amplitude')
164 #pyplot.savefig('ecg_fig10.eps', format='eps')

```

Listing 9: Filter operation and Filtered Time Domain Plot

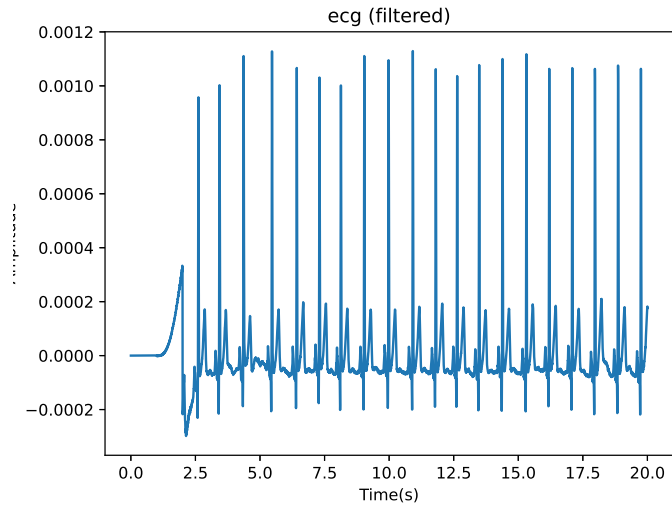


Figure 12: Filtered ECG from ECG.dat

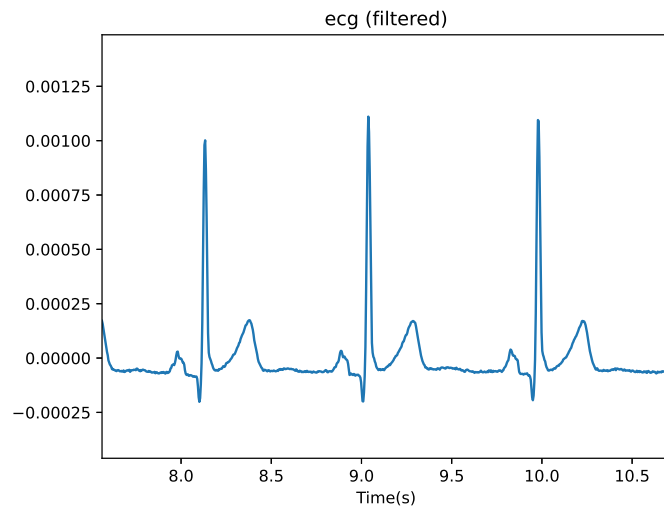


Figure 13: Partly ECG from ECG.dat

From figure 13, the ECG from the filter does still look intact.

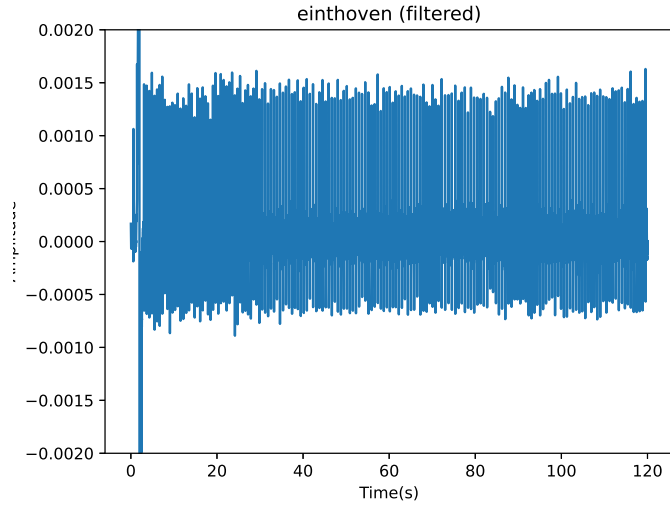


Figure 14: Filtered ECG from Einthoven.ii Walking

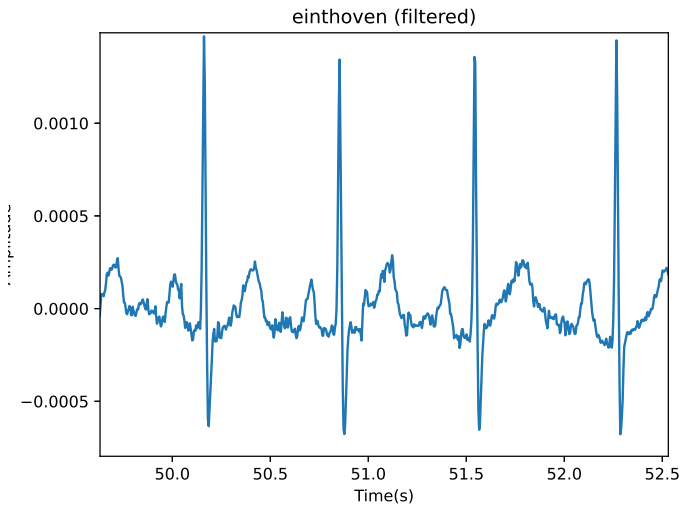


Figure 15: Partly Filtered ECG from Einthoven.ii Walking

We can see that the filtered plots are a lot cleaner and no DC line visible. The first part of both filtered ECGs are invalid because the filter is being filled up as mentioned earlier. There are about 2 heart beat loss. We saved the processed ECG data into another .dat file to be used for heart



rate detection.

```
177 #save filtered data
178 np.savetxt('shortecg.dat',filterecg)
179 np.savetxt('shorteint.dat',filtereinthoven)
```

Listing 10: Save .dat Files

### 1.3 Discussion

We can use ring buffer to reduce computation steps required from shifting operation.

```
1 '''
2 import numpy as np
3 # Inefficient way
4 class FIR_filter:
5     def __init__(self,coefficients):
6         self.coeff = coefficients
7         self.offset = 0
8         self.buffer = np.empty(len(coefficients))
9
10    def dofilter(self,u):
11        result = 0
12        for i in range(len(self.buffer)-1,0,1): #range(start,end,
13            step)
14            self.buffer[i+1] = self.buffer[i]
15            self.buffer[0] = u
16            for i in range(len(self.buffer)-1):
17                result = result + self.coeff[i] * self.buffer[i]
18        return result
19 '''
```

Listing 11: Not Using Ring Buffer Version

The fundamental frequency of the ECG starts around 1 Hz, so the cutoff frequency should be below 1 Hz to avoid eliminating the ECG signal itself.

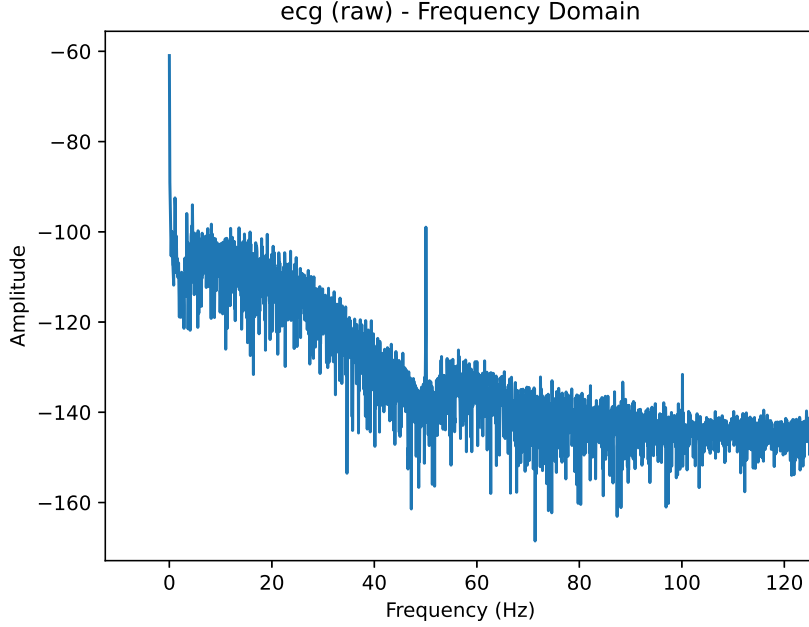


Figure 16: Raw ECG in Frequency Domain from ECG.dat

From figure 16, we could observe peak at 0 Hz (DC) and a peak at 50 Hz noise. The other spectrum amplitude is high near lower frequencies which implies that the ECG signal composes of lower frequencies. To conclude, from this frequency domain plot of the spectrum, we could decide on which cutoff frequencies should be used in our filter design.

## 2 HeartRate Detection

### 2.1 Introduction

Detecting heart-rate peaks from the ECG data requires a DC free signal, so we used the data processed from the previous `ecg_filter.py`. The template is created by trimming one of a PQRST from the corresponding ECG. Then inverse of the template is used as the coefficient of the FIR Filter. An anti-noise heartbeat algorithm is implemented to the code to prevent noise detected as an extra irregular heartbeat. Time difference from one peak to another is processed to get the beats per minute.

Einthoven ii walking ECG recording, which provides greater noise as a benchmark test of the noise filtering, is loaded to test the heart-rate detection program.

## 2.2 Method and Results

```
1 import numpy as np
2 from matplotlib import pyplot
3 from numpy import loadtxt
4 from fir_filter import FIR_filter
5
6 Case = 0
7 #Case = int(input("Case 0 For shortecg.dat. Case 1 For Einthoven_ii
8     Walking. Please enter case number: "))
9 for Case in range(2):
10     if Case == 0:
11         cleanecg = loadtxt("shortecg.dat")
12     if Case == 1:
13         cleanecg = loadtxt("shorteint.dat")
14
15     fs=250          #sampling frequency of the data
16
17     pyplot.figure(8*Case+1)
18     time = np.linspace(0,len(cleanecg)/fs,len(cleanecg))
19     pyplot.plot(time,cleanecg)
20     pyplot.title('ecg (filtered)')
21     pyplot.xlabel('Time(s)')
22     pyplot.ylabel('Amplitude')
23     # if Case == 0:
24     #     pyplot.savefig('hr_fig1.eps', format='eps')
25     # if Case == 1:
26     #     pyplot.savefig('hr_fig9.eps', format='eps')
27
28     #ecg templates for each data set
29     if Case == 0:
30         template=cleanecg[775:975]
31     if Case == 1:
32         template=cleanecg[7050:7225]
33
34     #plot template
35     pyplot.figure(8*Case+2)
36     time2 = np.linspace(0,len(template)/fs,len(template))
37     pyplot.plot(time2,template)
38     pyplot.title('1 ecg')
39     pyplot.xlabel('Time(s)')
40     pyplot.ylabel('Amplitude')
41     # if Case == 0:
42     #     pyplot.savefig('hr_fig2.eps', format='eps')
43     # if Case == 1:
44     #     pyplot.savefig('hr_fig10.eps', format='eps')
45
46     #inverse the template
47     fir_coeff = template[::-1]
48     pyplot.figure(8*Case+3)
49     pyplot.plot(time2,fir_coeff)
50     pyplot.title('reversed 1 ecg')
51     pyplot.xlabel('Time(s)')
52     pyplot.ylabel('Amplitude')
53     # if Case == 0:
54     #     pyplot.savefig('hr_fig3.eps', format='eps')
55     # if Case == 1:
```

```
55 # pyplot.savefig('hr_fig11.eps', format='eps')
```

Listing 12: Obtaining Coefficient for FIR filter

Two cases are implemented to switch between the shortecg.dat and the Einthoven II walking ECG. The templates were eye-observed from the graphs, and then trimmed for the length of one PQRST Complex. Then the template is inversed corresponding the x-axis.

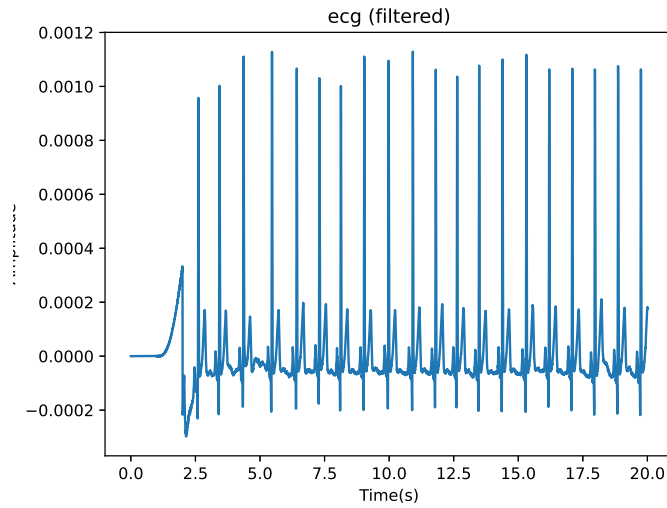


Figure 17: Filtered ECG from ECG.dat

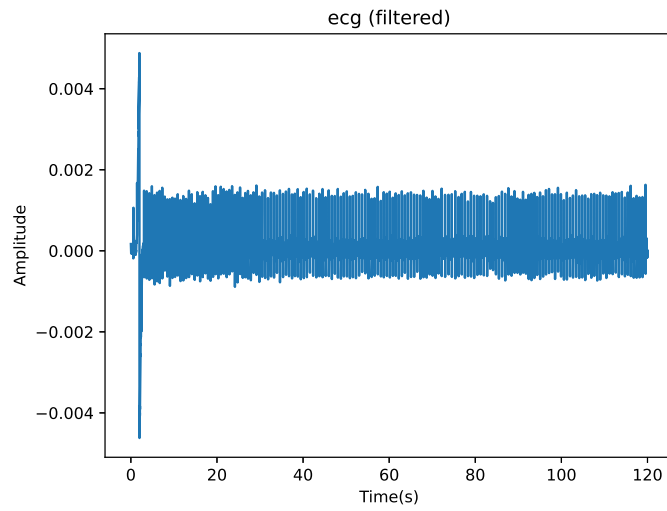


Figure 18: Filtered ECG from Einthoven.ii Walking

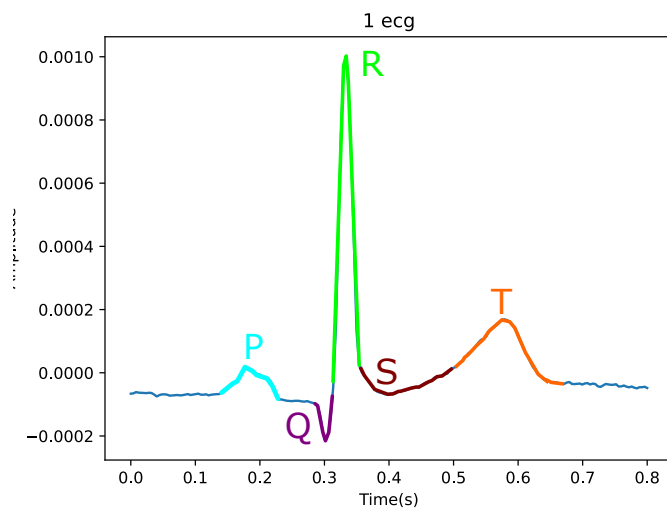


Figure 19: 1 ECG from ECG.dat

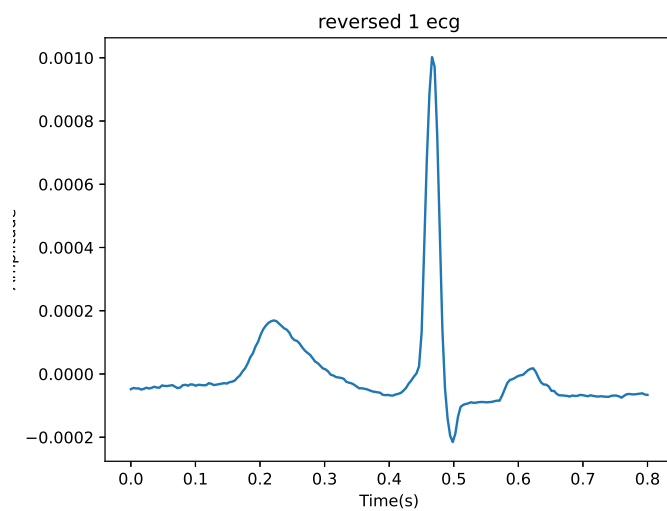


Figure 20: Reversed 1 ECG from ECG.dat

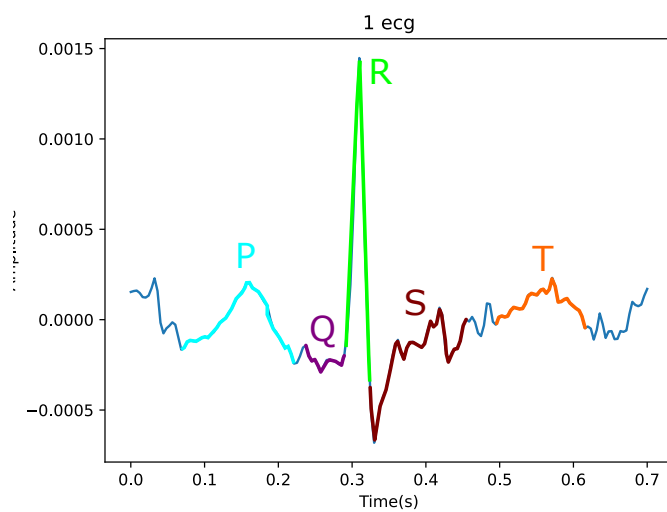


Figure 21: 1 ECG from Einthoven\_ii Walking

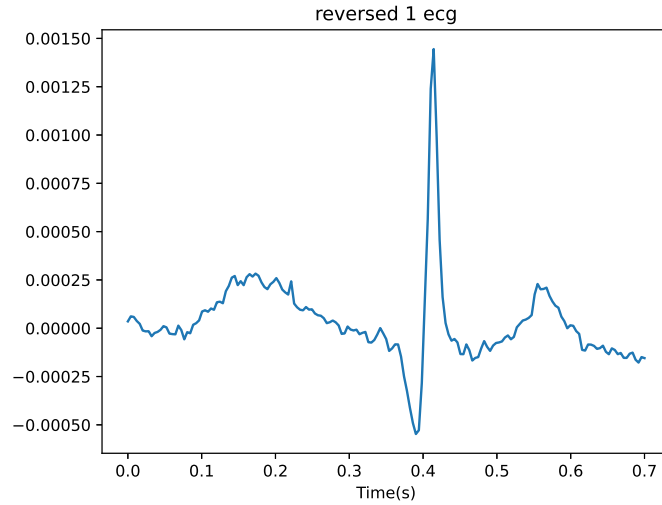


Figure 22: Reversed 1 ECG from Einthoven\_ii Walking

```

57 #matched filtered data
58 matchfilt = FIR_filter(fir_coeff)
59
60 matchresult = np.zeros(len(cleanecg))
61 for i in range(len(cleanecg)):
62     matchresult[i] = matchfilt.dofilter(cleanecg[i])
63
64 pyplot.figure(8*Case+4)
65 pyplot.plot(time,matchresult)
66 pyplot.title('Matched Filtered ecg')
67 pyplot.xlabel('Time(s)')
68 pyplot.ylabel('Amplitude')
69 # if Case == 0:
70 #     pyplot.savefig('hr_fig4.eps', format='eps')
71 # if Case == 1:
72 #     pyplot.savefig('hr_fig12.eps', format='eps')
73 print(len(matchresult))

```

Listing 13: Matched Filter Implementation

FIR Filter is used to perform matched filter. The coefficients are the inverted template, which is the **fir-coeff**.

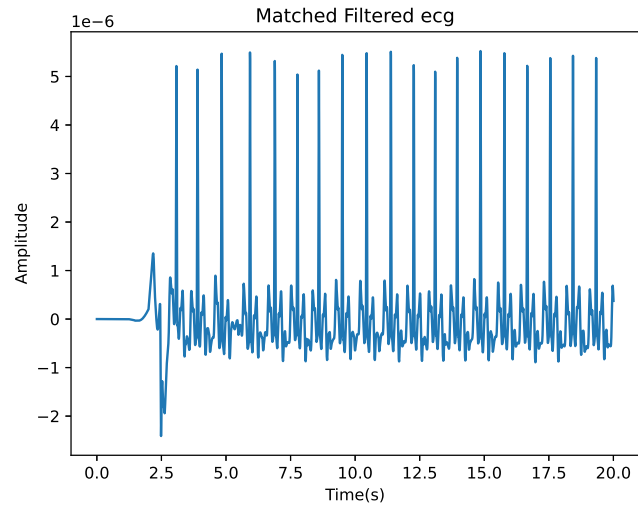


Figure 23: Match Filter Result from ECG.dat

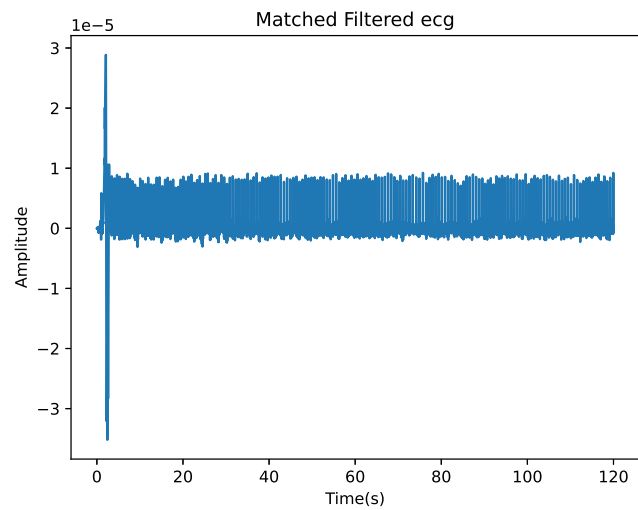


Figure 24: Match Filter Result from Einthoven.ii Walking

```

75 #squared matched filtered data
76 matchresult = matchresult*matchresult
77 pyplot.figure(8*Case+5)
78 pyplot.plot(time,matchresult) #
79 pyplot.title('Squared Matched Filtered ecg')

```



```

80     pyplot.xlabel('Time(s)')
81     pyplot.ylabel('Amplitude')
82     # if Case == 0:
83     #     pyplot.savefig('hr_fig5.eps', format='eps')
84     # if Case == 1:
85     #     pyplot.savefig('hr_fig13.eps', format='eps')

```

Listing 14: Squaring the Results

By squaring the matched results post-filter, the outcome of the data produces higher peak with lower noise.

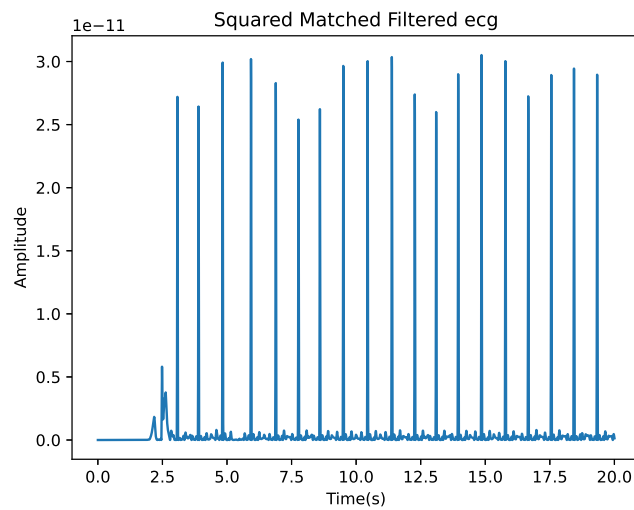


Figure 25: Squared Match Filter Result from ECG.dat

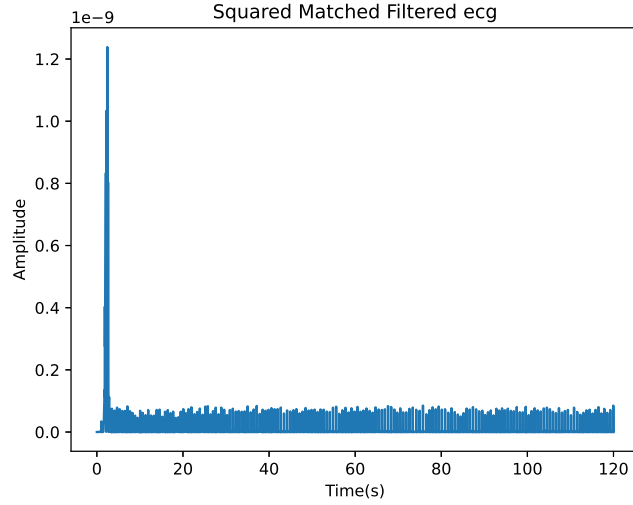


Figure 26: Squared Match Filter Result from Einthoven\_ii Walking

```

87 #using threshold to extract the peaks
88 hr = np.zeros(len(matchresult))
89 threshold = 0.00000000002
90 for i in range(len(matchresult)):
91     if matchresult[i]>threshold:
92         hr[i]=1
93
94 pyplot.figure(8*Case+6)
95 pyplot.plot(hr)
96 pyplot.title('Heart Beat Detection Sequence')
97 pyplot.xlabel('Sample number')
98 pyplot.ylabel('Amplitude')
99 #pyplot.xlim(3,120) #to delete the first part where
    the buffer is being filled/diagnosis purpose
100 # if Case == 0:
101 #     pyplot.savefig('hr_fig6.eps', format='eps')
102 # if Case == 1:
103 #     pyplot.savefig('hr_fig14.eps', format='eps')

```

Listing 15: Peak Threshold

The threshold used to detect the peaks of the data is around

$$2.0 * 10^{-11}$$

The value was observed from time domain plot of the squared matched result.

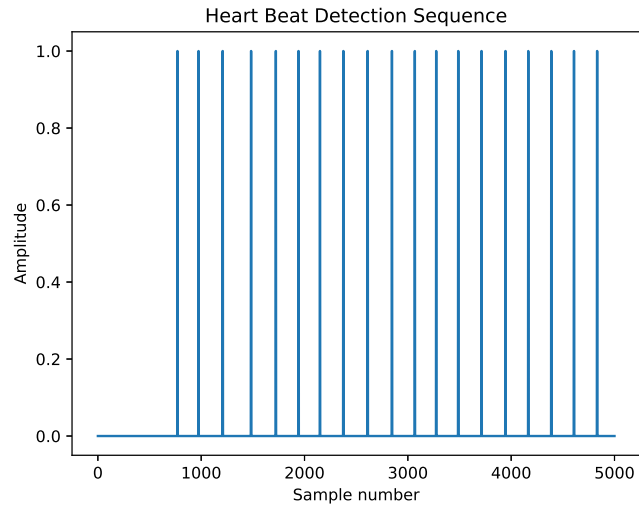


Figure 27: Heart Beat Extraction using Threshold from ECG.dat

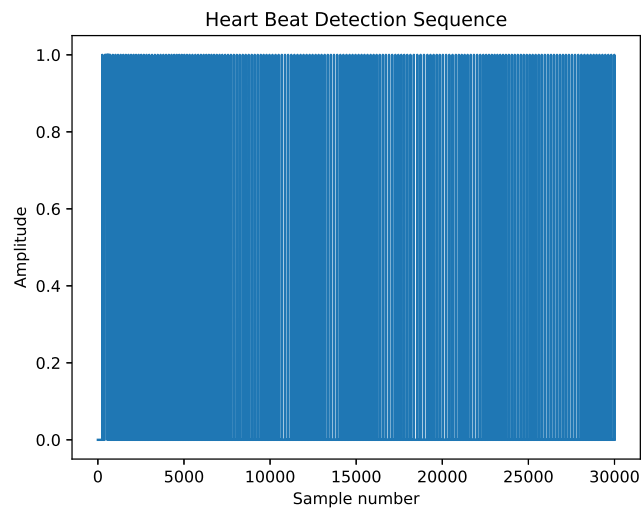


Figure 28: Heart Beat Extraction using Threshold from Einthoven\_ii Walking

```

105 #initiate counters
106 peakCounter = 0 #count number of peaks > for array size
107 detectIndex = 0 #detection index
108 deltatIndex = 0 #deltat index
109

```

```

110 index = np.zeros(len(hr))
111 threshT = int(1/(3.66/fs))    #3.66beat/s is the maximum heart
                                rate(220bpm)
112
113 for i in range(len(hr)):
114     if hr[i] == 1:
115         peakCounter+=1
116         for n in range(int(threshT)):    #fix the impossible
detected peak to 0
117             if i+n+1 <= 30000:          #If the time is less
than 30000
118                 hr[i+n+1] = 0
119
120 pyplot.figure(8*Case+7)
121 pyplot.plot(hr)
122 pyplot.title('Heart Beat Detection Sequence Fixed')
123 pyplot.xlabel('Sample number')
124 pyplot.ylabel('Amplitude')
125 #pyplot.xlim(3,120)    #to delete the first part where the
buffer is being filled/diagnosis purpose
126 # if Case == 0:
127 #     pyplot.savefig('hr_fig7.eps', format='eps')
128 # if Case == 1:
129 #     pyplot.savefig('hr_fig15.eps', format='eps')

```

Listing 16: Time Threshold

A time threshold **threshT** is used to delete unwanted/false 1s sequence between two peaks. A constant value of 3.66 beat/s is the highest heart-rate that would occur. The threshold is interpolated into the array index length. For any second detected 1s within that time threshold will be set to zero.

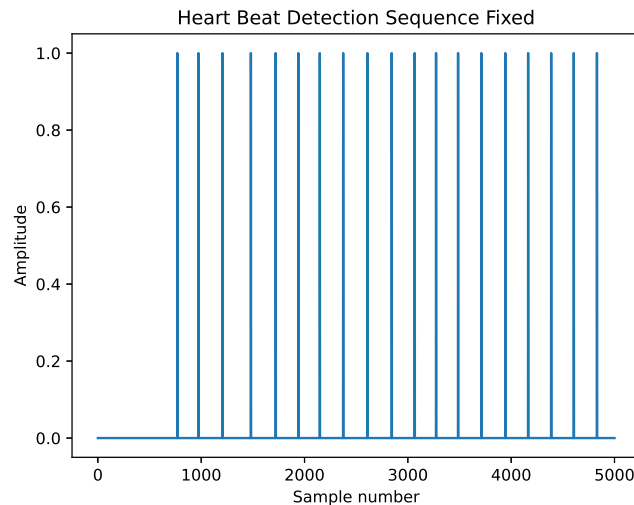


Figure 29: Heart Beat Extraction False 1s Deleted from ECG.dat

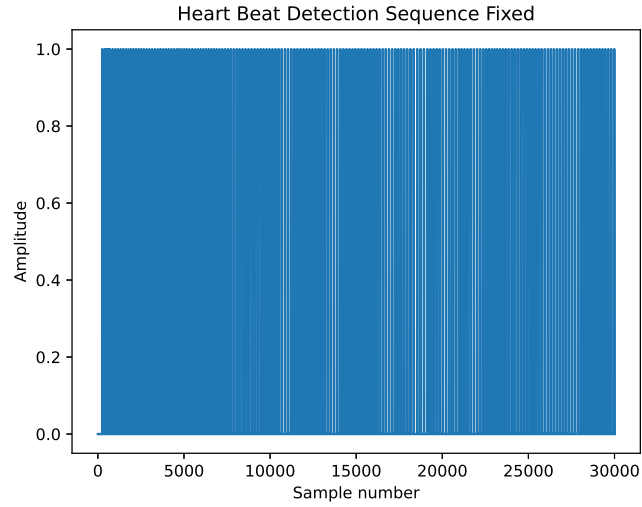


Figure 30: Heart Beat Extraction False 1s Deleted from Einthoven\_ii Walking

From figure 31, we can see the 1s from the sequence is more than 1 due to the use of amplitude threshold. It's then proven to be fixed in figure 32 with the correction algorithm. Any other false peak in between time threshold would also get deleted.

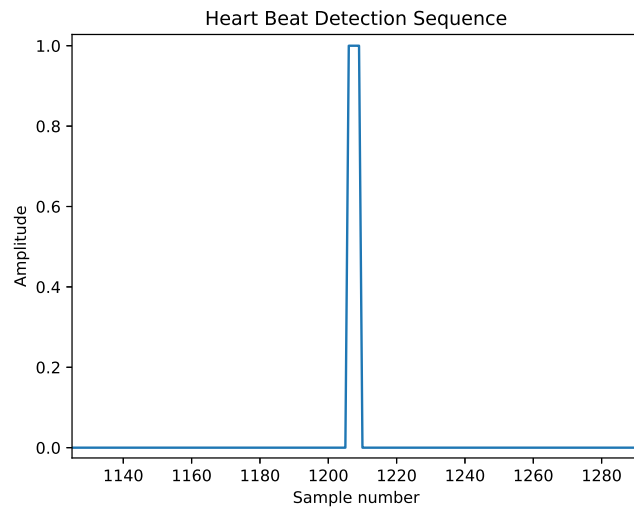


Figure 31: Partly Heart Beat Extraction using Threshold from ECG.dat

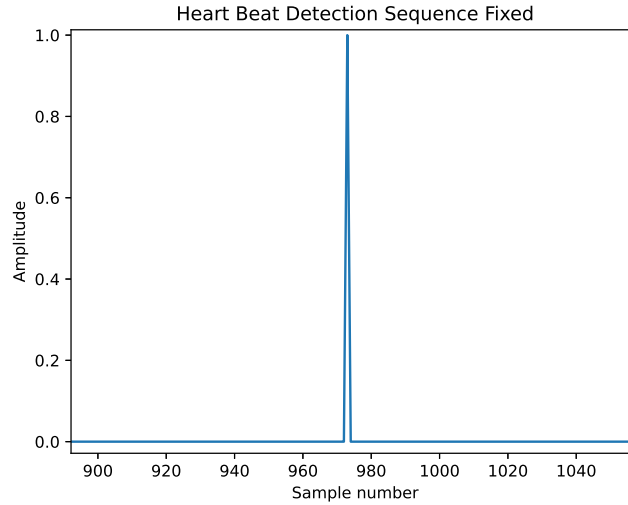


Figure 32: Partly Heart Beat Extraction False 1s Deleted from ECG.dat

```

131     beatone = np.zeros(peakCounter)
132     deltat = np.zeros(peakCounter)
133     rate = np.zeros(peakCounter)
134
135     print("Momentary Heart Rate(BPM)")
136     for i in range(len(hr)):
137         if hr[i] != 0:           # When element is not zero, input
138             element to new array
139             beatone[detectIndex] = i
140             detectIndex += 1
141             if detectIndex >= 0:   # To neglect the first
142                 detection
143                 deltat[deltatIndex] = (beatone[deltatIndex] -
144                 beatone[deltatIndex-1])/fs
145                 # print('ONE',beatone[deltatIndex])           #for
146                 diagnosis purpose
147                 # print('TWO',beatone[deltatIndex-1])
148                 # print('TIME',deltat[deltatIndex])
149                 rate[deltatIndex] = (1/deltat[deltatIndex])*60
150                 print(rate[deltatIndex])
151                 deltatIndex += 1
152
153     pyplot.figure(8*Case+8)
154     pyplot.plot(beatone/fs,rate)
155     pyplot.title('Heart Rate Plot')
156     pyplot.xlabel('Time(s)')
157     pyplot.ylabel('Beats/Minute')
158     #pyplot.xlim(4,max(beatone)/fs+1)           #to delete the first
159     part where the buffer is being filled/diagnosis purpose
160     # if Case == 0:
161     #     pyplot.savefig('hr_fig8.eps', format='eps')
162     # if Case == 1:

```

```
158 # pyplot.savefig('hr_fig16.eps', format='eps')
```

Listing 17: Momentary Heart Rate Calculation

To calculate the Momentary Heart Rate (BPM), the time difference **deltat** is extracted from the sequence and then calculated into BPM.

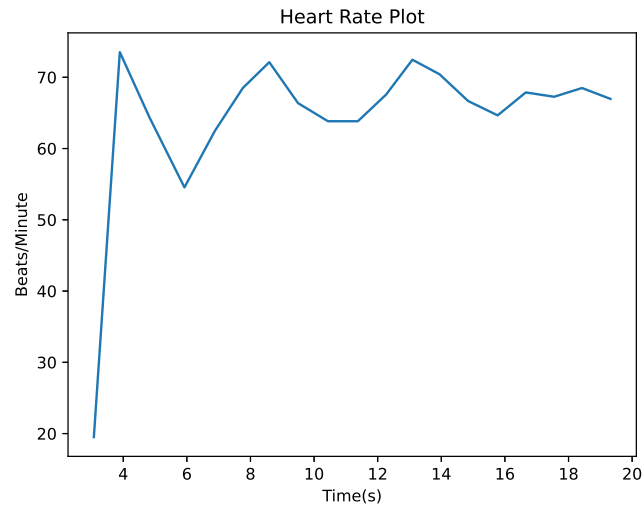


Figure 33: Momentary Heart Rate Plot from ECG.dat

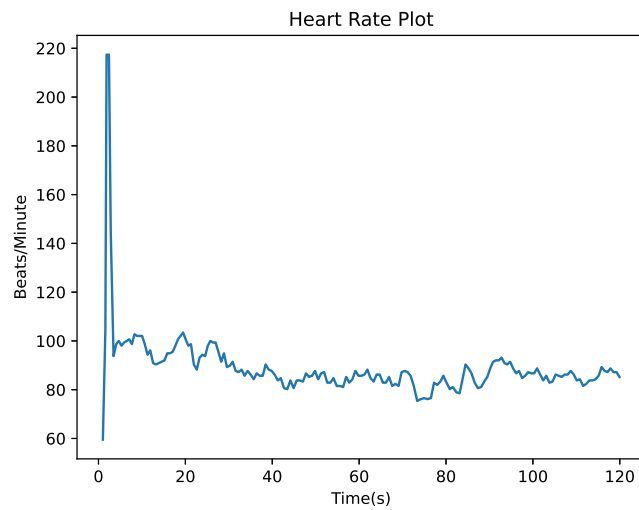


Figure 34: Momentary Heart Rate Plot from Einthoven.ii Walking

To comply with real-time processing, we have also implemented a real time heart rate detection python class using all above principle. Small changes are made to **deltat** and is replaced by **self.counter** which resets itself everytime a new peak is detected. The **threshold** also was lowered to make it be able to detect heart beat from eintoven ii data. Note that the data input into the filter instantiated from the class should be filtered by the 50 Hz notch and DC line elimination filter first. **And the file submitted would only run this part to display only the momentary rate graph. It also represents how it will be used in real application.** The result looks similar to figure 33 and figure 34, but only plotting at when the new heart beat has arrived and the momentary heart rate can be calculated.

```

161 class HR_filter:
162     def __init__(self,):
163         ecg = loadtxt("shortecg.dat")           #file which the
164         template is extracted from              #template is extracted from
165         template=ecg[775:975]                  #1ecg of the
166         corresponding file                      #corresponding file
167         fir_coeff = template[::-1]             #reverse template
168         self.matchfilt = FIR_filter(fir_coeff)
169         self.hr = 0
170         self.hrBuffer = 0                      #keep previous hr
171         value for peak starts checking         #value for peak starts checking
172         self.counter = 0                       #counts time
173         difference before next peak arrive     #difference before next peak arrive
174
175     def realtimeHR(self,data,fs):
176         matchresult = self.matchfilt.dofilter(data)
177         matchresult = matchresult*matchresult
178         threshold = 0.000000000001            #observed by eye
179         from graph
180
181         #use threshold to extract peak area
182         if matchresult>threshold:
183             self.hr=1
184         else:
185             self.hr=0
186
187         threshT = int(1/(3.66/fs))             #3.66beat/s is the
188         maximum heart rate(220bpm)            #maximum heart rate(220bpm)
189         rate=0                                 #default argument
190
191         #checks if the peak starts
192         if self.hrBuffer==0 and self.hr==1:
193             #peak=1 #for diagnosis purpose : peak starts
194             if self.counter>threshT:
195                 rate = (fs/self.counter)*60
196                 self.counter=0                 #reset counter
197             return rate
198         else:
199             #peak=0 #for diagnosis purpose : no peak starting
200             self.counter+=1
201             return None
202         #return matchresult
203         self.hrBuffer = self.hr                #save value for

```



```

future comparison
198
199
200 #Example Use
201 data = loadtxt("shortecg.dat")
202 data2 = loadtxt("shorteint.dat")
203 fs=250
204 mhr = np.zeros(len(data))
205 mhr2 = np.zeros(len(data2))
206 hrfilt = HR_filter() #instantiate the
    HR_filter
207 for i in range(len(data)):
208     mhr[i] = hrfilt.realtimeHR(data[i],fs)
209 for i in range(len(data2)):
210     mhr2[i] = hrfilt.realtimeHR(data2[i],fs)
211
212 pyplot.figure(17)
213 pyplot.plot(np.linspace(0,len(data)/fs,len(data)),mhr)
214 pyplot.title('Momentary Heart Rate Plot from ECG.dat')
215 pyplot.xlabel('Time(s)')
216 pyplot.ylabel('Beats/Minute')
217 #pyplot.savefig('hr_fig17.eps', format='eps')
218
219 pyplot.figure(18)
220 pyplot.plot(np.linspace(0,len(data2)/fs,len(data2)),mhr2)
221 pyplot.title('Momentary Heart Rate Plot from einthoven II')
222 pyplot.xlabel('Time(s)')
223 pyplot.ylabel('Beats/Minute')
224 #pyplot.savefig('hr_fig18.eps', format='eps')

```

Listing 18: Momentary Heart Rate Calculation

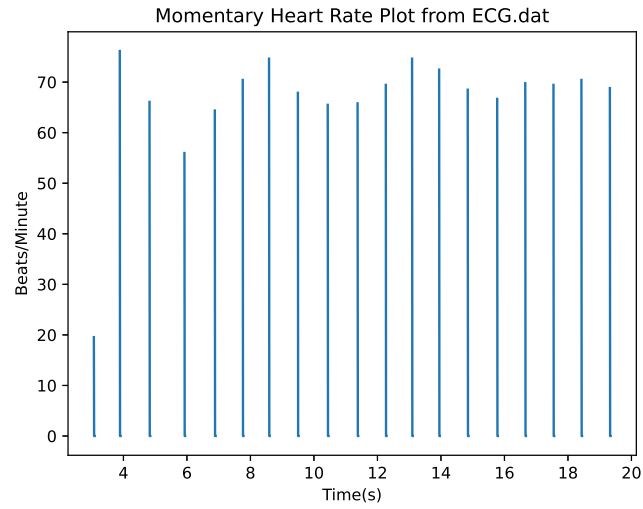


Figure 35: Momentary Heart Rate Plot from shortecg.dat using filter class implemented

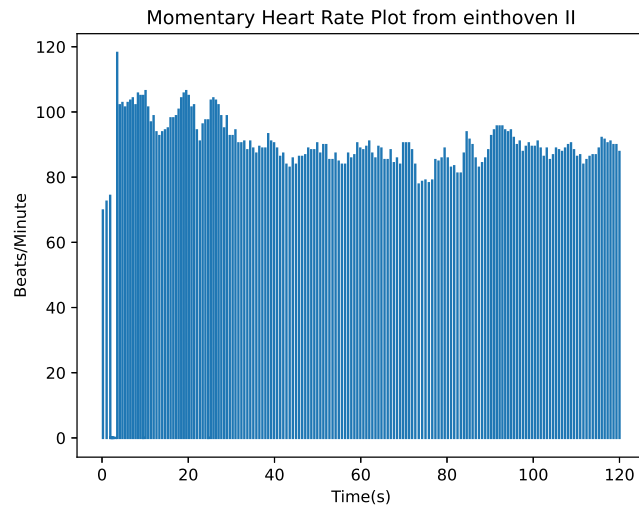


Figure 36: Momentary Heart Rate Plot from shorteint.dat using filter class implemented

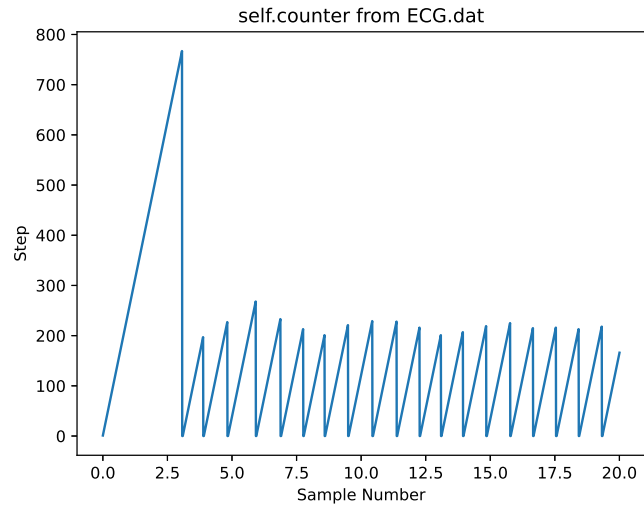


Figure 37: self.counter Uses of Detecting Heart Beat from shortecg.dat

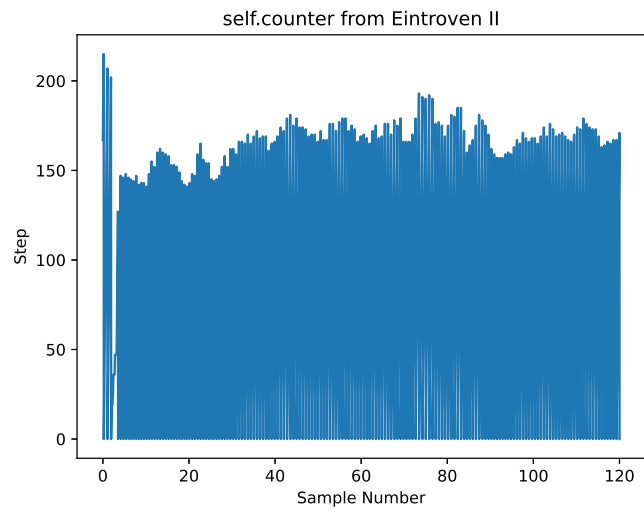


Figure 38: self.counter Uses of Detecting Heart Beat from shorteint.dat

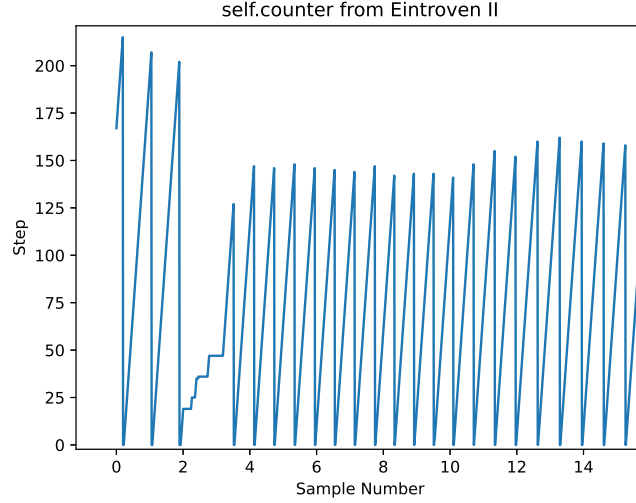


Figure 39: Partly self.counter Uses of Detecting Heart Beat from shorteint.dat

## 2.3 Discussion

Figure 20 shows the use of time-inversed template for the matched filter, as it indicates PQRST points on the template. The template is time-reversed to fulfil the requirements to perform convolution with the input signal. The template taken from one of the PQRST complex is then used as the coefficient to perform a matched filter to the data. Results of the match filter on figure 23 shows an increase of the ratio of the peaks to the noise. After squaring the data, a threshold is applied to the data to capture the peaks, which can be seen on figure 27. The detected sequence are in form of an array which consists of ones and zeros. The detected heart-rate plot on figure 32 shows the trends of the Beats Per Minute under 20 seconds of the sampled data.

The Einthoven II walking data is presumed to have greater noise occurring throughout the 50Hz, which may disrupt the R-peak detection. On figure 21 we indicate the PQRST complex on the template sampled from the Einthoven II which looks obviously more noisy than that of the shortecg.dat one. Figure 24 is the reversed template. Under the same process alike the shortecg.dat data, we use square matched filter and thresholds application to refine the peaks of the beats. After the calculation of the Beats/Minute, the momentary heart rate plot is shown on figure 28 within 120 seconds. Note that the array taken to complete the full buffer invalidate the value on the early times when the buffer is being filled up. Again, a trade-off is introduced between frequency resolution and the length of data being invalidated by the buffer.

We can actually use a same template for any data as demonstrated by the python class implemented. It doesn't matter which data the template is ex-

tracted from, but the template must represent an ECG signal(with all the ECG artefacts/PQRST).

As the outcome, the python class instantiated filter successfully detected the heartrate of the Einthoven II walking with lower **threshold**.

In addition, we tried to plot the raw vs. filtered data of a more noisy database. From figure 40, the raw data in orange obviously demonstrate a DC line shift, while the filtered one line shift is eliminated by the filters applied in `ecg_filter.py`. When it is used in `hr_detect.py`, the line shift will not affect the matched filter result.

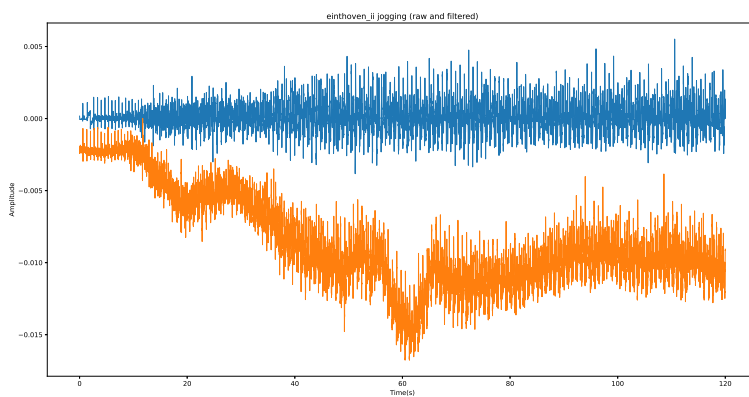


Figure 40: Raw vs. Filtered data from Einthoven\_ii Jogging

## 3 Appendix

### 3.1 fir\_filter.py

```

1  '''
2  import numpy as np
3  # Inefficient way
4  class FIR_filter:
5      def __init__(self,coefficients):
6          self.coeff = coefficients
7          self.offset = 0
8          self.buffer = np.empty(len(coefficients))
9
10     def dofilter(self,u):
11         result = 0
12         for i in range(len(self.buffer)-1,0,1): #range(start,end,
13             step)
14             self.buffer[i+1] = self.buffer[i]
15             self.buffer[0] = u
16             for i in range(len(self.buffer)-1):
17                 result = result + self.coeff[i] * self.buffer[i]

```

```

17         return result
18
19     '''
20     import numpy as np
21     class FIR_filter:
22         def __init__(self,coefficients):
23             self.coeff = coefficients
24             self.offset = 0
25             self.buffer = np.zeros(len(coefficients))
26
27         def dofilter(self,u):
28             result = 0
29             self.buffer[self.offset] = u
30             #print("offset index:",self.offset)
31
32             for i in range(self.offset+1):
33                 result = result + self.buffer[i]*self.coeff[self.offset
-i]
34
35                 #print("buffer index:",i)
36                 #print("coeff index:",self.offset-i)
37
38                 #print("Second For Section")
39                 for i in range(self.offset+1,len(self.buffer),1):
40                     result = result + self.buffer[i]*self.coeff[len(self.
buffer)-1+self.offset+1-i]
41                     #print("buffer index:",i)
42                     #print("coeff index:",len(self.buffer)-1+self.offset+1-
i)
43
44                     self.offset+=1
45                     if self.offset>=len(self.buffer):
46                         self.offset=0
47
48                     return result
49
50         def dofilterPrint(self,u):          #index printing version for
diagnosis purpose
51             result = 0
52             self.buffer[self.offset] = u
53             print("offset index:",self.offset)
54
55             for i in range(self.offset+1):
56                 result = result + self.buffer[i]*self.coeff[self.offset
-i]
57
58                 print("buffer index:",i)
59                 print("coeff index:",self.offset-i)
60
61                 print("Second For Section")
62                 for i in range(self.offset+1,len(self.buffer),1):
63                     result = result + self.buffer[i]*self.coeff[len(self.
buffer)-1+self.offset+1-i]
64                     print("buffer index:",i)
65                     print("coeff index:",len(self.buffer)-1+self.offset+1-i
)
66
67                     self.offset+=1
68                     if self.offset>=len(self.buffer):

```

```

67         self.offset=0
68
69         return result
70
71 def unittest():
72     h = np.array([1/2,1/2,0,0,0])
73     print("Coefficient:",h)
74     f = FIR_filter(h)
75     y= f.dofilterPrint(0)          #use the index printing version
76     print("Input 0, Output",y)
77     y= f.dofilterPrint(1)          #use the index printing version
78     print("Input 1, Output",y)
79     for i in range (20):
80         y= f.dofilterPrint(0)      #use the index printing version
81         print("Input 0, Output",y)
82
83 if __name__ == "__main__":
84     unittest()

```

Listing 19: fir\_filter.py

### 3.2 ecg\_filter.py

```

1 from ecg_gudb_database import GUDb
2 import numpy as np
3 from fir_filter import FIR_filter
4 from numpy import loadtxt
5 from matplotlib import pyplot
6
7 fs = 250      #Hz
8 M = 500      #loses 2 heart beat to warm up the filter (2seconds)/
              #affect frequency resolution
9
10 # 50 Hz Notch Filter
11 k1 = int(49.5/fs * M)
12 k2 = int(50.5/fs * M)
13
14 Window50 = np.ones(M)
15 Coeff50 = np.ones(M)
16
17 Window50[k1:k2+1] = 0
18 Window50[M-k2:M-k1+1] = 0
19
20 pyplot.figure(1)
21 pyplot.plot(Window50)
22 pyplot.title('50 Hz Notch Filter - Ideal')
23 pyplot.xlabel('M (sample number)')
24 pyplot.ylabel('Amplitude')
25 # pyplot.savefig('ecg_fig1.eps', format='eps')
26
27 W50 = np.fft.ifft(Window50)
28 W50 = np.real(W50)
29
30 pyplot.figure(2)
31 pyplot.plot(W50)
32 pyplot.title('50 Hz Notch Filter - IFFT')

```

```

33 pyplot.xlabel('Coefficient Index')
34 pyplot.ylabel('Amplitude')
35 # pyplot.savefig('ecg_fig2.eps', format='eps')
36
37 Coeff50[0:int(M/2)] = W50[int(M/2):M]
38 Coeff50[int(M/2):M] = W50[0:int(M/2)]
39
40 pyplot.figure(3)
41 pyplot.plot(Coeff50)
42 pyplot.title('50 Hz Notch Filter - IFFT(fixed)')
43 pyplot.xlabel('Coefficient Index')
44 pyplot.ylabel('Amplitude')
45 # pyplot.savefig('ecg_fig3.eps', format='eps')
46
47 Filter50 = FIR_filter(Coeff50)
48
49
50 #DC filter
51 k3 = int(0.5/fs * M)
52 WindowDC = np.ones(M)
53 CoeffDC = np.ones(M)
54
55 WindowDC[0:k3+1] = 0
56 pyplot.figure(4)
57 pyplot.plot(WindowDC)
58 pyplot.title('DC Filter - Ideal')
59 pyplot.xlabel('M (sample number)')
60 pyplot.ylabel('Amplitude')
61 # pyplot.savefig('ecg_fig4.eps', format='eps')
62
63 WDC = np.fft.ifft(WindowDC)
64 WDC = np.real(WDC)
65
66 pyplot.figure(5)
67 pyplot.plot(WDC)
68 pyplot.title('DC Filter - IFFT')
69 pyplot.xlabel('Coefficient Index')
70 pyplot.ylabel('Amplitude')
71 # pyplot.savefig('ecg_fig5.eps', format='eps')
72
73 CoeffDC[0:int(M/2)] = WDC[int(M/2):M]
74 CoeffDC[int(M/2):M] = WDC[0:int(M/2)]
75
76 pyplot.figure(6)
77 pyplot.plot(CoeffDC)
78 pyplot.title('DC Filter - IFFT(fixed)')
79 pyplot.xlabel('Coefficient Index')
80 pyplot.ylabel('Amplitude')
81 # pyplot.savefig('ecg_fig6.eps', format='eps')
82
83 FilterDC = FIR_filter(CoeffDC)
84
85
86 # load first ECG file
87 file1 = open('ECG.dat', 'r') #line by line to use as real-time
    filter
88

```



```

89 ecg = loadtxt("ECG.dat")           #for diagnosis plot
90
91 pyplot.figure(7)
92 #print(len(ecg))
93 time = np.linspace(0,len(ecg)/fs,len(ecg))
94 pyplot.plot(time,ecg)
95 pyplot.title('ecg (raw)')
96 pyplot.xlabel('Time(s)')
97 pyplot.ylabel('Amplitude')
98 # pyplot.savefig('ecg_fig7.eps', format='eps')
99
100
101 # Investigate frequency domain
102 fx=np.fft.fft(ecg)
103 fxx = fx/len(ecg)           # Fourier Transform Normalised
104 dbs = 20*np.log10(abs(fxx)) # DB Conversion
105 pyplot.figure(8)
106 freq = np.linspace(0,fs,len(ecg))
107 pyplot.plot(freq,dbs)
108 pyplot.title('ecg (raw) - Frequency Domain')
109 pyplot.xlabel('Frequency (Hz)')
110 pyplot.ylabel('Amplitude')
111 # pyplot.savefig('ecg_fig8.eps', format='eps')
112
113 #load second ECG data
114 '''Initialise experiments from the files of einthoven'''
115 subject_number = 3
116 experiment = 'walking'
117 ecg_class = GUDb(subject_number, experiment)
118
119 '''Initialise experiments from the files of einthoven'''
120 chest_strap_V2_V1 = ecg_class.cs_V2_V1
121 einthoven_ii = ecg_class.einthoven_II
122
123 '''Filtered Data With Einthoven'''
124 ecg_class.filter_data()
125 einthoven_ii_filt = ecg_class.einthoven_II_filt
126
127 #define output array and intermediate variable
128 filterecg = np.zeros(len(ecg)+1)
129 filtereinthoven = np.zeros(len(einthoven_ii)+1)
130 intermediate = 0
131
132 #filter ecg for both data sets
133 count = 0
134 for line in file1:
135     count += 1
136     ecg1 = line.strip()
137     #print(ecg1)
138     intermediate = Filter50.dofilter(ecg1)
139     filterecg[count] = FilterDC.dofilter(intermediate)
140
141 for i in range(len(einthoven_ii)):
142     intermediate = Filter50.dofilter(einthoven_ii[i])
143     filtereinthoven[i] = FilterDC.dofilter(intermediate)
144
145 #print(count)

```

```

146
147 #plot the filtered data
148 pyplot.figure(9)
149 time2 = np.linspace(0,len(filterecg)/fs,len(filterecg))
150 pyplot.plot(time2,filterecg)
151 #pyplot.ylim(-0.002,0.002)
152 pyplot.title('ecg (filtered)')
153 pyplot.xlabel('Time(s)')
154 pyplot.ylabel('Amplitude')
155 # pyplot.savefig('ecg_fig9.eps', format='eps')
156
157 pyplot.figure(10)
158 time3 = np.linspace(0,len(filtereinthoven)/fs,len(filtereinthoven))
159 pyplot.plot(time3,filtereinthoven)
160 pyplot.ylim(-0.002,0.002)
161 pyplot.title('einthoven (filtered)')
162 pyplot.xlabel('Time(s)')
163 pyplot.ylabel('Amplitude')
164 # pyplot.savefig('ecg_fig10.eps', format='eps')
165
166
167 pyplot.figure(11)
168 #print(len(einthoven_ii))
169 time4 = np.linspace(0,len(einthoven_ii)/fs,len(einthoven_ii))
170 pyplot.plot(time4,einthoven_ii)
171 pyplot.title('einthoven_ii (raw)')
172 pyplot.xlabel('Time(s)')
173 pyplot.ylabel('Amplitude')
174 # pyplot.savefig('ecg_fig11.eps', format='eps')
175
176
177 #save filtered data
178 np.savetxt('shortecg.dat',filterecg)
179 np.savetxt('shorteint.dat',filtereinthoven)

```

Listing 20: ecg\_filter.py

### 3.3 hr\_detect.py

```

1 import numpy as np
2 from matplotlib import pyplot
3 from numpy import loadtxt
4 from fir_filter import FIR_filter
5 '''
6 Case = 0
7 #Case = int(input("Case 0 For shortecg.dat. Case 1 For Einthoven_ii
      Walking. Please enter case number: "))
8 for Case in range (2):
9     if Case == 0:
10         cleanecg = loadtxt("shortecg.dat")
11     if Case == 1:
12         cleanecg = loadtxt("shorteint.dat")
13
14     fs=250          #sampling frequency of the data
15
16     pyplot.figure(8*Case+1)

```

```

17     time = np.linspace(0,len(cleanecg)/fs,len(cleanecg))
18     pyplot.plot(time,cleanecg)
19     pyplot.title('ecg (filtered)')
20     pyplot.xlabel('Time(s)')
21     pyplot.ylabel('Amplitude')
22     # if Case == 0:
23     #     pyplot.savefig('hr_fig1.eps', format='eps')
24     # if Case == 1:
25     #     pyplot.savefig('hr_fig9.eps', format='eps')
26
27     #ecg templates for each data set
28     if Case == 0:
29         template=cleanecg[775:975]
30     if Case == 1:
31         template=cleanecg[7050:7225]
32
33     #plot template
34     pyplot.figure(8*Case+2)
35     time2 = np.linspace(0,len(template)/fs,len(template))
36     pyplot.plot(time2,template)
37     pyplot.title('1 ecg')
38     pyplot.xlabel('Time(s)')
39     pyplot.ylabel('Amplitude')
40     # if Case == 0:
41     #     pyplot.savefig('hr_fig2.eps', format='eps')
42     # if Case == 1:
43     #     pyplot.savefig('hr_fig10.eps', format='eps')
44
45     #inverse the template
46     fir_coeff = template[::-1]
47     pyplot.figure(8*Case+3)
48     pyplot.plot(time2,fir_coeff)
49     pyplot.title('reversed 1 ecg')
50     pyplot.xlabel('Time(s)')
51     pyplot.ylabel('Amplitude')
52     # if Case == 0:
53     #     pyplot.savefig('hr_fig3.eps', format='eps')
54     # if Case == 1:
55     #     pyplot.savefig('hr_fig11.eps', format='eps')
56
57     #matched filtered data
58     matchfilt = FIR_filter(fir_coeff)
59
60     matchresult = np.zeros(len(cleanecg))
61     for i in range(len(cleanecg)):
62         matchresult[i] = matchfilt.dofilter(cleanecg[i])
63
64     pyplot.figure(8*Case+4)
65     pyplot.plot(time,matchresult)
66     pyplot.title('Matched Filtered ecg')
67     pyplot.xlabel('Time(s)')
68     pyplot.ylabel('Amplitude')
69     # if Case == 0:
70     #     pyplot.savefig('hr_fig4.eps', format='eps')
71     # if Case == 1:
72     #     pyplot.savefig('hr_fig12.eps', format='eps')
73     print(len(matchresult))

```

```

74
75 #squared matched filtered data
76 matchresult = matchresult*matchresult
77 pyplot.figure(8*Case+5)
78 pyplot.plot(time,matchresult) #
79 pyplot.title('Squared Matched Filtered ecg')
80 pyplot.xlabel('Time(s)')
81 pyplot.ylabel('Amplitude')
82 # if Case == 0:
83 #     pyplot.savefig('hr_fig5.eps', format='eps')
84 # if Case == 1:
85 #     pyplot.savefig('hr_fig13.eps', format='eps')
86
87 #using threshold to extract the peaks
88 hr = np.zeros(len(matchresult))
89 threshold = 0.00000000002
90 for i in range(len(matchresult)):
91     if matchresult[i]>threshold:
92         hr[i]=1
93
94 pyplot.figure(8*Case+6)
95 pyplot.plot(hr)
96 pyplot.title('Heart Beat Detection Sequence')
97 pyplot.xlabel('Sample number')
98 pyplot.ylabel('Amplitude')
99 #pyplot.xlim(3,120) #to delete the first part where
    the buffer is being filled/diagnosis purpose
100 # if Case == 0:
101 #     pyplot.savefig('hr_fig6.eps', format='eps')
102 # if Case == 1:
103 #     pyplot.savefig('hr_fig14.eps', format='eps')
104
105 #initiate counters
106 peakCounter = 0 #count number of peaks > for array size
107 detectIndex = 0 #detection index
108 deltatIndex = 0 #deltat index
109
110 index = np.zeros(len(hr))
111 threshT = int(1/(3.66/fs)) #3.66beat/s is the maximum heart
    rate(220bpm)
112
113 for i in range(len(hr)):
114     if hr[i] == 1:
115         peakCounter+=1
116         for n in range(int(threshT)): #fix the impossible
    detected peak to 0
117             if i+n+1 <= 30000: #If the time is less
    than 30000
118                 hr[i+n+1] = 0
119
120 pyplot.figure(8*Case+7)
121 pyplot.plot(hr)
122 pyplot.title('Heart Beat Detection Sequence Fixed')
123 pyplot.xlabel('Sample number')
124 pyplot.ylabel('Amplitude')
125 #pyplot.xlim(3,120) #to delete the first part where the
    buffer is being filled/diagnosis purpose

```

```

126 # if Case == 0:
127 #     pyplot.savefig('hr_fig7.eps', format='eps')
128 # if Case == 1:
129 #     pyplot.savefig('hr_fig15.eps', format='eps')
130
131 beatone = np.zeros(peakCounter)
132 deltat = np.zeros(peakCounter)
133 rate = np.zeros(peakCounter)
134
135 print("Momentary Heart Rate(BPM)")
136 for i in range(len(hr)):
137     if hr[i] != 0:          # When element is not zero, input
        element to new array
138         beatone[detectIndex] = i
139         detectIndex += 1
140         if detectIndex >= 0:          # To neglect the first
            detection
141             deltat[deltatIndex] = (beatone[deltatIndex] -
            beatone[deltatIndex-1])/fs
142             # print('ONE',beatone[deltatIndex])          #for
            diagnosis purpose
143             # print('TWO',beatone[deltatIndex-1])
144             # print('TIME',deltat[deltatIndex])
145             rate[deltatIndex] = (1/deltat[deltatIndex])*60
146             print(rate[deltatIndex])
147             deltatIndex += 1
148
149 pyplot.figure(8*Case+8)
150 pyplot.plot(beatone/fs,rate)
151 pyplot.title('Heart Rate Plot')
152 pyplot.xlabel('Time(s)')
153 pyplot.ylabel('Beats/Minute')
154 #pyplot.xlim(4,max(beatone)/fs+1)          #to delete the first
            part where the buffer is being filled/diagnosis purpose
155 # if Case == 0:
156 #     pyplot.savefig('hr_fig8.eps', format='eps')
157 # if Case == 1:
158 #     pyplot.savefig('hr_fig16.eps', format='eps')
159 '''
160
161 class HR_filter:
162     def __init__(self,):
163         ecg = loadtxt("shortecg.dat")          #file which the
            template is extracted from
164         template=ecg[775:975]          #1ecg of the
            corresponding file
165         fir_coeff = template[::-1]          #reverse template
166         self.matchfilt = FIR_filter(fir_coeff)
167         self.hr = 0
168         self.hrBuffer = 0          #keep previous hr
            value for peak starts checking
169         self.counter = 0          #counts time
            difference before next peak arrive
170
171     def realtimeHR(self,data,fs):
172         matchresult = self.matchfilt.dofilter(data)
173         matchresult = matchresult*matchresult

```

```

174     threshold = 0.00000000001          #observed by eye
175     from graph
176
177     #use threshold to extract peak area
178     if matchresult>threshold:
179         self.hr=1
180     else:
181         self.hr=0
182
183     threshT = int(1/(3.66/fs))          #3.66beat/s is the
184     maximum heart rate(220bpm)          #default argument
185     rate=0
186
187     #checks if the peak starts
188     if self.hrBuffer==0 and self.hr==1:
189         #peak=1          #for diagnosis purpose : peak starts
190         if self.counter>threshT:
191             rate = (fs/self.counter)*60
192             self.counter=0              #reset counter
193         return rate
194     else:
195         #peak=0          #for diagnosis purpose : no peak starting
196         self.counter+=1
197         return None
198     #return matchresult
199     self.hrBuffer = self.hr            #save value for
200     future comparison
201
202 #Example Use
203 data = loadtxt("shortecg.dat")
204 data2 = loadtxt("shorteint.dat")
205 fs=250
206 mhr = np.zeros(len(data))
207 mhr2 = np.zeros(len(data2))
208 hrfilt = HR_filter()                  #instantiate the
209 HR_filter
210 for i in range(len(data)):
211     mhr[i] = hrfilt.realtimeHR(data[i],fs)
212 for i in range(len(data2)):
213     mhr2[i] = hrfilt.realtimeHR(data2[i],fs)
214
215 pyplot.figure(17)
216 pyplot.plot(np.linspace(0,len(data)/fs,len(data)),mhr)
217 pyplot.title('Momentary Heart Rate Plot from ECG.dat')
218 pyplot.xlabel('Time(s)')
219 pyplot.ylabel('Beats/Minute')
220 #pyplot.savefig('hr_fig17.eps', format='eps')
221
222 pyplot.figure(18)
223 pyplot.plot(np.linspace(0,len(data2)/fs,len(data2)),mhr2)
224 pyplot.title('Momentary Heart Rate Plot from einthoven II')
225 pyplot.xlabel('Time(s)')
226 pyplot.ylabel('Beats/Minute')
227 #pyplot.savefig('hr_fig18.eps', format='eps')

```

Listing 21: hr\_detect.py

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