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1 Oppgave

1.1 a

Har prosessen,

$$x(t) = x_1(t) + x_2(t) \quad (1)$$

,disse er *ukorrelerte* og *stasjon  re* prosesser.

Vi har Wiener-Khinchin theoremene,

$$S_{xx}(f) = \mathcal{F}\{R_{xx}(\tau)\} = \int_{-\infty}^{\infty} R_{xx}(\tau) e^{-i2\pi f\tau} d\tau \quad (2)$$

$$R_{xx}(\tau) = \mathcal{F}^{-1}\{S_{xx}(f)\} = \int_{-\infty}^{\infty} S_{xx}(f) e^{i2\pi f\tau} df \quad (3)$$

Her er \mathcal{F} Fourier transformasjon. Bruker at,

$$R_{xx}(\tau) = E[x_{t+\tau}x_t] \quad (4)$$

L  ser vi denne med tanke p   ligning (1) f  r vi,

$$R_{xx}(\tau) = E[(x_1(t+h) + x_2(t+h))(x_1(t) + x_2(t))] \quad (5)$$

Som gir,

$$R_{xx}(\tau) = E[x_1(t+h)x_1(t)] + E[x_1(t+h)x_2(t+h)] + E[x_1(t+h)x_2(t)] + E[x_2(t+h)x_2(t)] \quad (6)$$

Siden prosessene er ukorrelerte vil man kunne separere forventingene, $E[x_1(t+h)]E[x_2(t+h)]$

Dette gir da,

$$R_{xx}(\tau) = E[x_1(t+h)x_1(t)] + E[x_1(t+h)]E[x_2(t+h)] + E[x_1(t+h)]E[x_2(t)] + E[x_2(t+h)x_2(t)] \quad (7)$$

Dette kan separeres slik at,

$$R_{xx}(\tau) = E[x_1(t+h)x_1(t)] + E[x_1(t+h)]E[x_2(t+h)] + E[x_1(t+h)]E[x_2(t)] + E[x_2(t+h)x_2(t)] \quad (8)$$

Siden $R_{x_1x_1}(\tau) = E[x_1(t+\tau)x_1(t)]$ f  r vi,

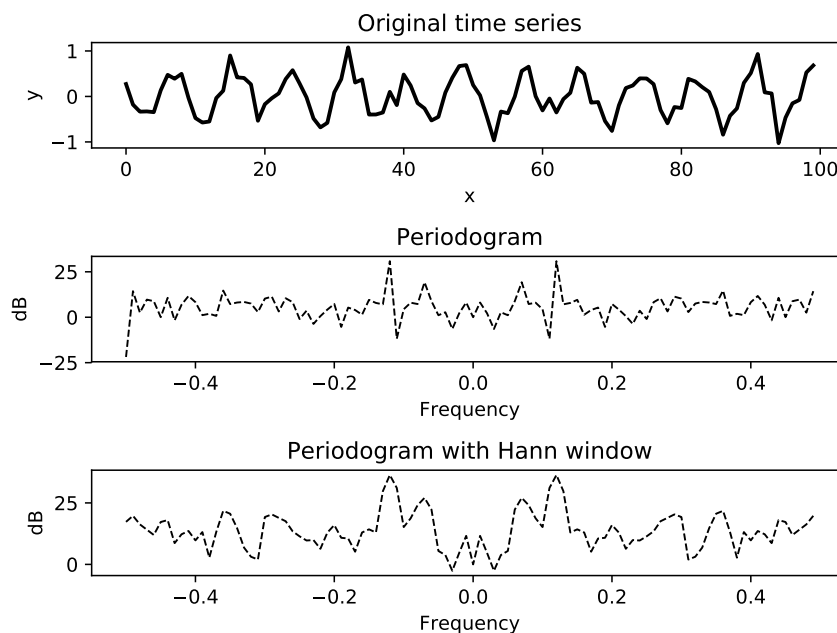
$$R_{xx}(\tau) = R_{x_1x_1}(\tau) + E[x_1(t+h)]E[x_2(t+h)] + E[x_1(t+h)]E[x_2(t)] + R_{x_2x_2}(\tau) \quad (9)$$

Siden vi har summer kan vi d  le integralet opp i sum,

$$S_{xx}(f) = \underbrace{\int_{-\infty}^{\infty} R_{x_1x_1}(\tau) e^{-i2\pi f\tau} d\tau}_{=S_{x_1x_1}(f)} + \underbrace{\int_{-\infty}^{\infty} R_{x_2x_2}(\tau) e^{-i2\pi f\tau} d\tau}_{=S_{x_2x_2}(f)} \quad (10)$$

1.2 b

I figur(1) ser vi tidsrekken i   verste vindu, periodogram, og periodogram med hann vindu.



Figur 1: Beregnet periodogram av tidsrekken.

Her ser man at hann vinduet gir en glattere kurve, og lar ikke frekvenser lekke over like mye som i det vanlige periodogrammet. Frekvensene ser ut til      re 0.1 og 0.05.

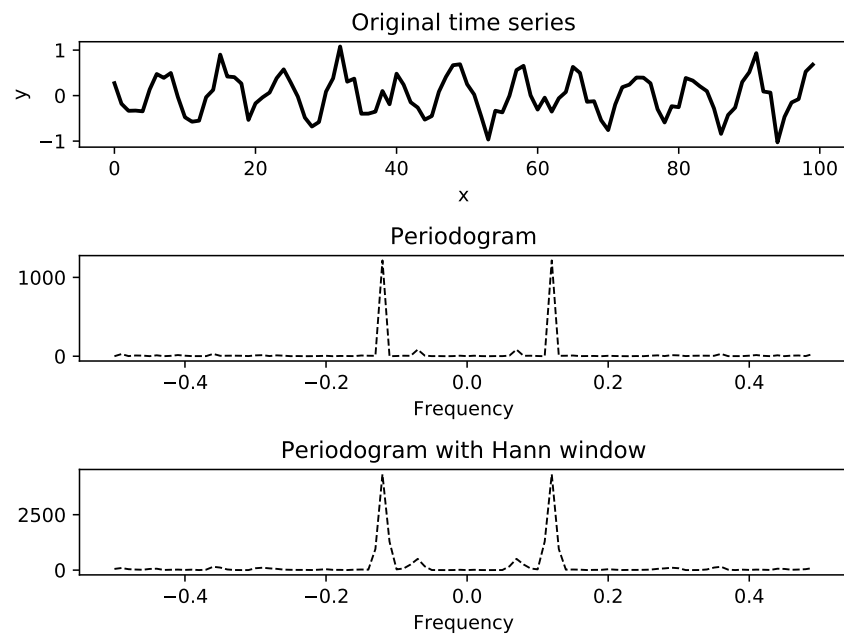
1.3 c

Som nevnt i oppgave b s   fjerner vinduet mer av lekkasje i frekvensspekteret, grunnet at den har lavere sidel  ber enn den idelle $w[k] = 1$, men dette vil   ke bredden p   hovedloben slik at man f  r litt d  rligere oppl  sning. I figure(2) har jeg ikke brukt dB skala slik at differansen er st  rre mellom styrken p   frekvensene. Her kan man tydelig se at vinduet hjelper med    se svakere periodisitet i spectrumet.

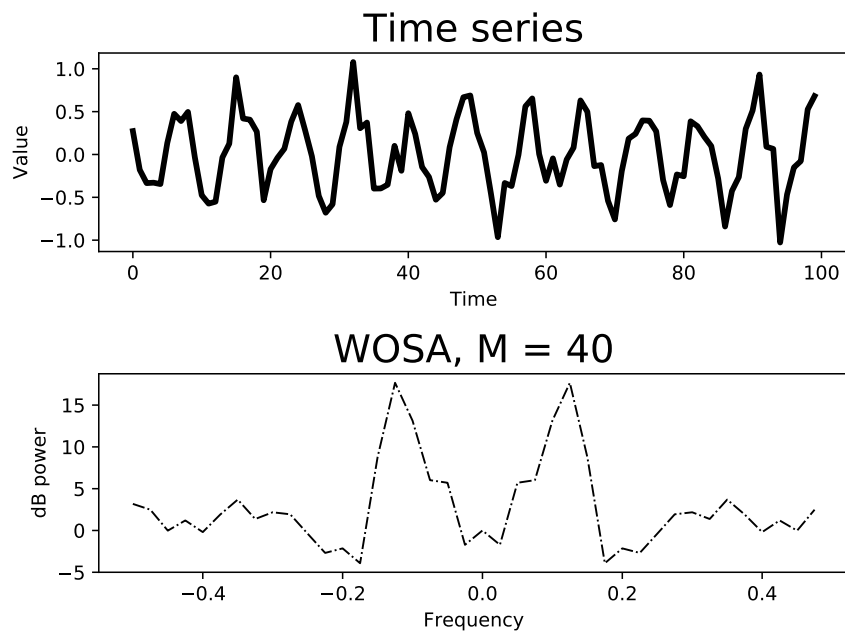
1.4 d

Ved    implementere WOSA (Weighted/Welchs overlapped segment averaging) p   tidsrekken fikk man resultatet vist i figur(3).

Her ble hver av segment vektet som gir et kraftigere utslag der det var sterke periodisiteter i forhold til resten av spekteret. Her ser man at frekvensen ≈ 0.1 er sv  rt kraftig og ≈ 0.05 viser seg ogs   ganske kraftig i forhold til alle de andre. Man kan se at frekvensene er mye tydeligere i WOSA enn i periodogrammet og hann vinduet i dB skala som vist i figur(1).



Figur 2: Beregnet periodogram av tidsrekken uten dB skala.

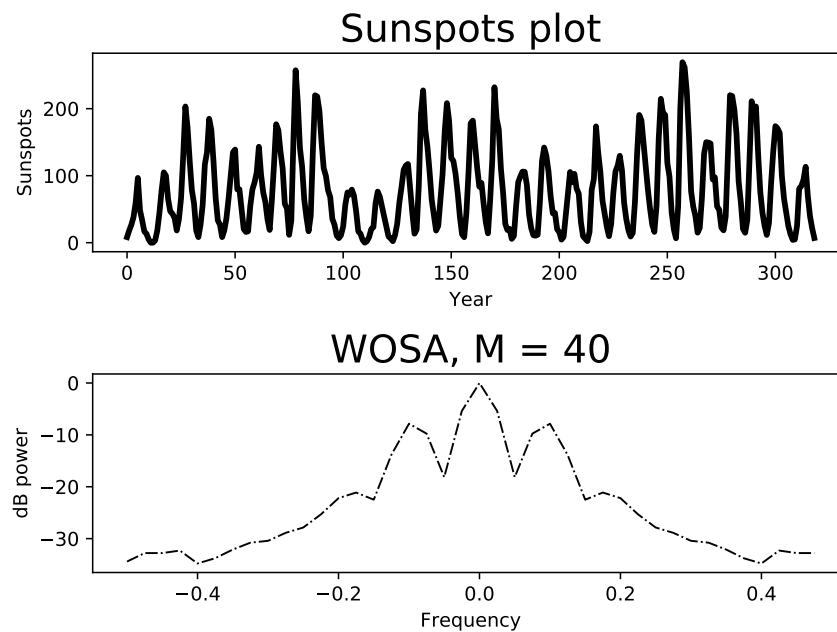


Figur 3: WOSA med 50% overlapp, $N = 40$

2 2

2.1 a-b

Her plottet vi sol-dataen som vist i   rste vindu i figur(4).



Figur 4: Soldata, WOSA med 50% overlapp, $N = 40$

Her ble det brukt WOSA med 50% overlapp og vindu-st  rrelse $N = 40$. Her ser man sterk DC og en frekvens p   rundt 0.1, $f \approx 0.1$. Dette gir en periode p   $T \approx 10$, noe som ser ut til    stemme hvis man teller antall topper som er ≈ 9 per 100.

3 Appendix

```

1 import numpy as np
2 import matplotlib.pyplot as plt
3
4
5 data = np.genfromtxt('tidsrekke_oblig2_oppg1.txt')
6
7
8 def periodogram(x, dt):
9     """Regular periodogram"""
10    N = len(x)
11    spectrum = np.abs(np.fft.fftshift(np.fft.fft(x))**2)
12    spectrum *= dt/ N
13    freq = np.fft.fftshift(np.fft.fftfreq(N, dt))
14
15    return freq, spectrum
16
17
18 def w_periodogram(x, dt):
19     """Windowed periodogram"""
20    N = len(x)
21    n = np.arange(0,N,1)
22    # Hann window
23    window = (1/2)*(1 - np.cos(2*np.pi*n/(N-1)))
24    U = (1/N)*np.sum(window**2)
25    spectrum = np.abs(np.fft.fftshift(np.fft.fft(window*x))**2)
26    spectrum *= (dt/(N*U))
27    freq = np.fft.fftshift(np.fft.fftfreq(N, dt))
28    return freq, spectrum
29
30 dt = 1
31 freq, spectrum = periodogram(data, dt)
32 freqw, wspectrum = w_periodogram(data, dt)
33
34 # Find index corresponding to f = 0
35 idx = np.where(freq == 0)
36 widx = np.where(freqw == 0)
37
38 # Plot
39 fig, ax = plt.subplots(3,1)
40 ax[0].plot(data, color = 'black', linewidth = 2)
41 ax[0].set_title('Original time series')
42 ax[0].set_xlabel('x')
43 ax[0].set_ylabel('y')
44 ax[1].plot(freq, 10*np.log10(spectrum/spectrum[idx]), '--', color = 'black',
45 linewidth = 1)
46 ax[1].set_title('Periodogram')
47 ax[1].set_xlabel('Frequency')
48 ax[1].set_ylabel('dB')
49 ax[2].plot(freqw, 10*np.log10(wspectrum/wspectrum[widx]), '--', color = 'black',
50 linewidth = 1)
51 ax[2].set_title('Periodogram with Hann window')
52 ax[2].set_xlabel('Frequency')
53 ax[2].set_ylabel('dB')
54 plt.tight_layout()
55 plt.savefig('rapport/taskb.pdf', bbox_inches = 'tight',
56 pad_inches = 0)
57 plt.show()

```

Figur 5: Task 1B-C


```

1  import matplotlib.pyplot as plt
2  import numpy as np
3
4  # Load file
5  data = np.genfromtxt('tidsrekke_oblig2_oppg1.txt')
6
7
8  def WOSA(x, M, dt = 1):
9      """Implementation of WOSA"""
10     n = np.arange(0, M, 1)
11     window = (1/2)*(1 - np.cos(2*np.pi*n/(M-1)))
12     U = (1/M)*np.sum(window**2)
13     spectrum = np.zeros(M)
14     n_windows = 2*int(len(x)/(M-1))
15     for i in range(n_windows):
16
17         # Start with window 0-40
18         if i == 0:
19             spectrum_temp = np.fft.fftshift(np.fft.fft(window*x[0:40]))
20             plt.plot(x[0:40])
21             t = np.arange(0, 40, 1)
22             plt.plot(t, window)
23
24
25         # Start overlapping
26         else:
27             spectrum_temp = np.fft.fftshift(np.fft.fft(window*x[(i*int(M/2)):(i
+2)*int(M/2)]))
28             plt.plot(x[(i+2)*int(M/2)])
29             t = np.arange((i*int(M/2)), (i+2)*int(M/2), 1)
30             plt.plot(t, window)
31             spectrum += (dt/(M*U))*np.abs(spectrum_temp)**2
32     spectrum /= n_windows
33     plt.show()
34     freq = np.fft.fftshift(np.fft.fftfreq(M, dt))
35     print('Number of windows: %s'%n_windows)
36     return freq, spectrum
37
38     M = 40
39     dt = 1
40     freq, spectrum = WOSA(data, M)
41     # Find index corresponding to f = 0
42     idx = np.where(freq == 0)
43
44     # Plot
45     fig, ax = plt.subplots(2,1)
46     ax[0].plot(data, linewidth = '3', color = 'black')
47     ax[0].set_title('Time series', fontsize = '20')
48     ax[0].set_ylabel('Value')
49     ax[0].set_xlabel('Time')
50     ax[1].plot(freq, 10*np.log10(spectrum/spectrum[idx]), '-', linewidth = '1',
color = 'black')
51     ax[1].set_title('WOSA, M = %s'%M, fontsize = '20')
52     ax[1].set_xlabel('Frequency')
53     ax[1].set_ylabel('dB power')
54     #ax[1].set_xlim([0,1/(2*dt)])
55     plt.tight_layout()
56     plt.savefig('rapport/taskd.pdf', bbox_inches = 'tight',
pad_inches = 0)
57     plt.show()
58
59

```

Figur 6: Task D

```

1 import os
2 import pandas as pd
3 import numpy as np
4 import matplotlib.pyplot as plt
5
6 filedir = os.path.dirname(__file__)
7 filename = 'SN_y_tot_V2.0.txt'
8
9 file = os.path.join(filedir, filename)
10
11 # load file
12 datatable = pd.read_csv(file, sep='\t', header=None, engine='python')
13 time = np.zeros(len(datatable))
14 sunspots = np.zeros(len(datatable))
15
16 for i in range(len(datatable)):
17     time[i] = datatable.values[i,0][0:6]
18     sunspots[i] = datatable.values[i,0][8:13]
19
20
21 def WOSA(x, M, dt = 1):
22     """Implementation of WOSA"""
23     n = np.arange(0, M, 1)
24     window = (1/2)*(1 - np.cos(2*np.pi*n/(M-1)))
25     U = (1/M)*np.sum(window**2)
26     spectrum = np.zeros(M)
27     n_windows = 2*int(len(x)/(M-1))-1
28     x = np.pad(x, (0, M), 'constant')
29     for i in range(n_windows):
30         # Start with window 0-40
31         if i == 0:
32             spectrum_temp = np.fft.fftshift(np.fft.fft(window*x[0:40]))
33             plt.plot(x[0:40])
34             t = np.arange(0, 40, 1)
35             plt.plot(t, 200*window)
36
37         # Start overlapping
38         else:
39             spectrum_temp = np.fft.fftshift(np.fft.fft(window*x[(i*int(M/2)):(i
40 +2)*int(M/2)]))
41             plt.plot(x[0:(i+2)*int(M/2)])
42             t = np.arange((i*int(M/2)), (i+2)*int(M/2), 1)
43             plt.plot(t, 200*window)
44             spectrum += (dt/(M*U))*np.abs(spectrum_temp)**2
45         spectrum /= n_windows
46         freq = np.fft.fftshift(np.fft.fftfreq(M, dt))
47         print('Number of windows: %s'%n_windows)
48         return freq, spectrum
49
50 M = 40
51 dt = 1
52 freq, spectrum = WOSA(sunspots, M)
53 # Find index corresponding to f = 0
54 idx = np.where(freq == 0)
55
56 # plot
57 fig, ax = plt.subplots(2,1)
58 ax[0].plot(sunspots, linewidth = '3', color = 'black')
59 ax[0].set_title('Sunspots plot', fontsize = '20')
60 ax[0].set_ylabel('Sunspots')
61 ax[0].set_xlabel('Year')
62 ax[1].plot(freq, 10*np.log10(spectrum/spectrum[idx]), '--', linewidth = '1',
63 color = 'black')
64 ax[1].set_title('WOSA, M = %s'%M, fontsize = '20')
65 ax[1].set_xlabel('Frequency')
66 ax[1].set_ylabel('dB power')
67 #ax[1].set_xlim([0,1/(2*dt)])
68 plt.tight_layout()
69 plt.savefig('rapport/task2.pdf', bbox_inches = 'tight',
70 pad_inches = 0)
71 plt.show()

```

Figur 7: Task 2 code

4 Referanser