Your solutions must be converted to PDF format. If you complete your work on paper, youcan take pictures of your solutions. Make sure that **the resolution is high** enough that your solutions are clear and legible.

Please start a new problem on a new page.

Copy and paste the MATLAB ***figures*** into the PDF file you are submitting.

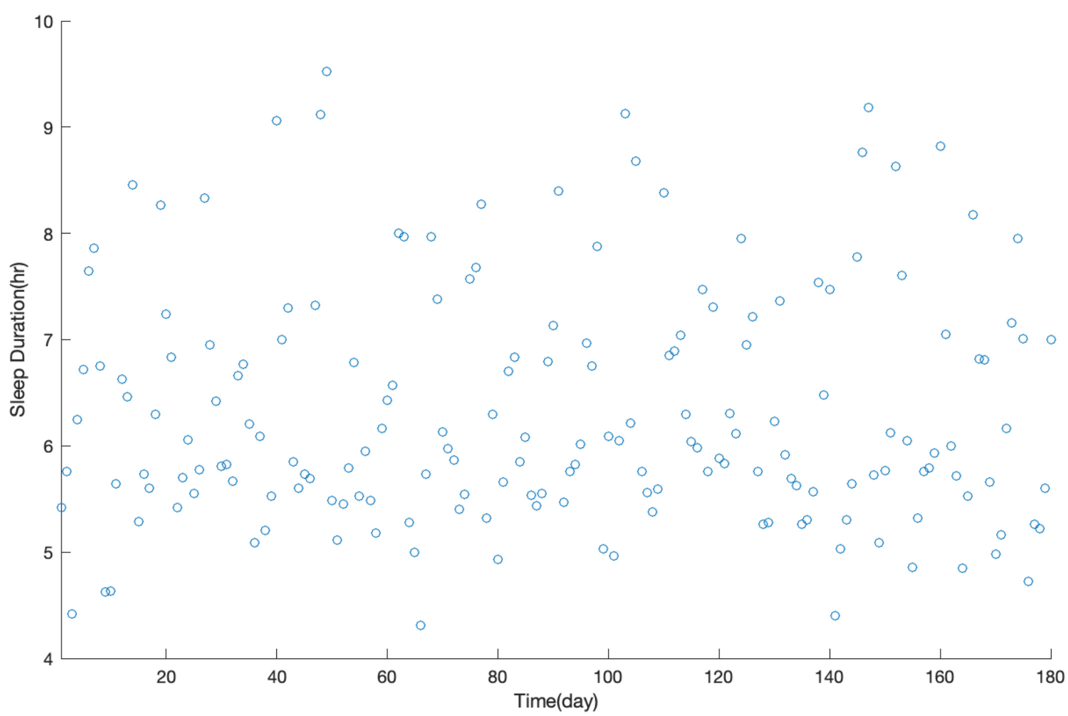
Copy and paste your MATLAB ***code*** at the end of the PDF file you are submitting. Submit your solutions on **Gradescope**.

42-302/42-782, Fall 2021 **DUE: 10/22/2021, 5:00 PM EST**

Homework 4

1. **[Total: 23 pts]** A non-engineering student read an article about sleep and its crucial role in memory retention and learning and became curious of his own sleep behavior. He had data of his sleep duration over the past 6 months, collected from his smartwatch. However, hedoes not know what to make of it. Help him analyze his sleep data.

   a) **[2 pts]** The sleep duration data in hours (`sleephours`) were collected every day for 180 days and can be found in `sleep.mat`. Use `scatter()` function to plot sleep duration asa function of time in days, starting from day 1.

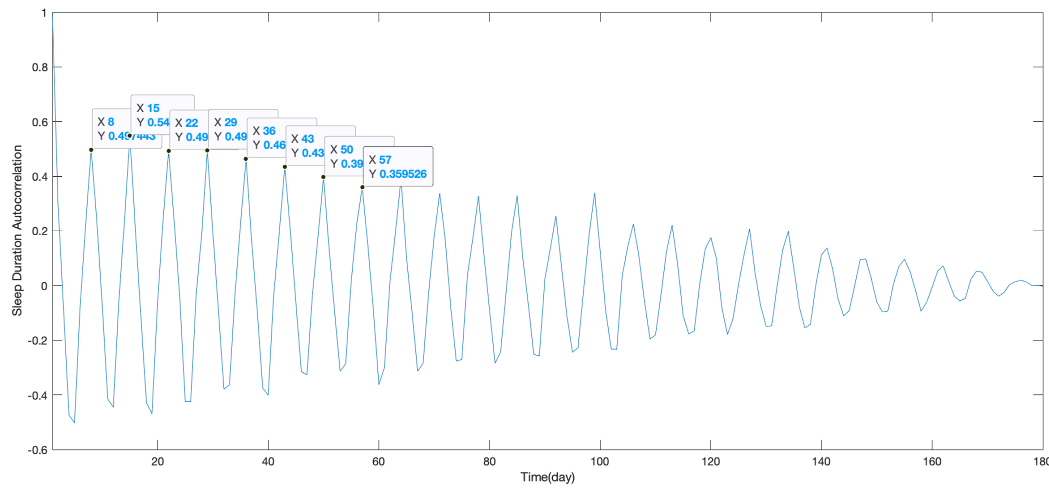


   b) **[2 pts]** Compute (using MATLAB) and report the average sleep duration. Report up to 2 decimal places.

The average sleep duration is around 6.32 hrs.

c) **[3 pts]** Use autocorrelation to reveal the intrinsic periodicity in the data (if any). Compute and plot the autocorrelation of the sleep duration. Use `xcorr()` function in MATLAB with `'coeff'` normalization option (such that the autocorrelation function at zero lag is 1). Label the axes of your plot. The unit of the x-axis should be in days.

Hint: We want to find whether there exists a rhythm in **the fluctuations in the sleep duration around its mean value**.

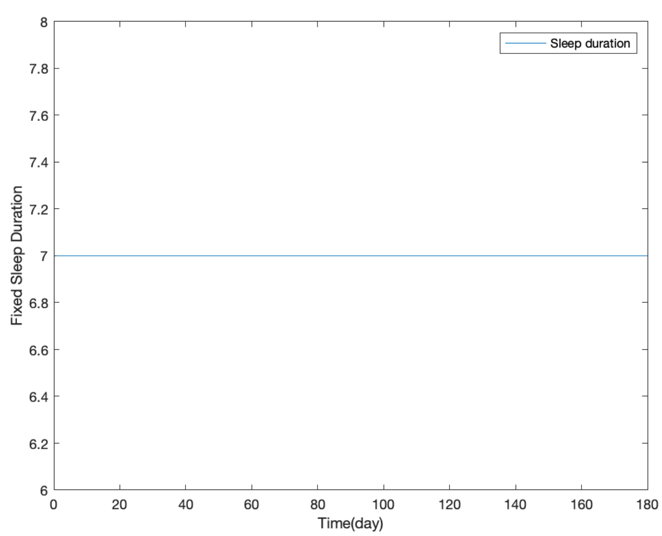


d) **[4 pts]** From the plot in 1c), is there any periodicity in the sleep duration? If so, determine the period of the present rhythm(s). Briefly explain how you arrived at your answers.

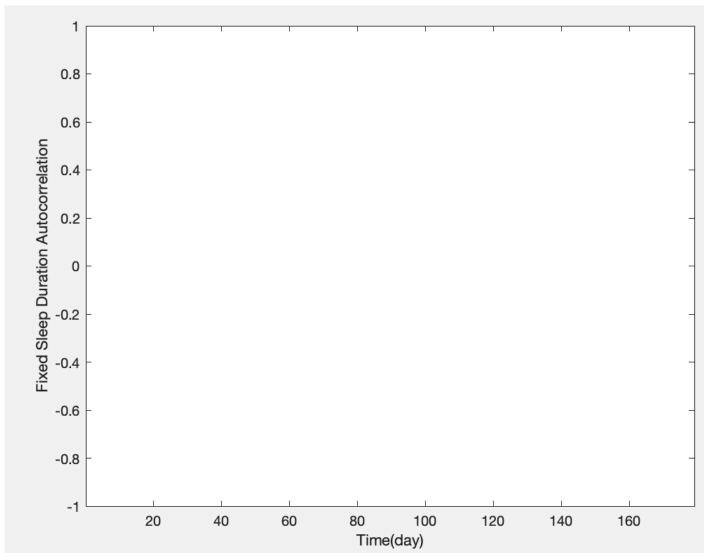
Yes. The rhythm is 7 days. The time interval between each peak is 7 days.

e) If this student were to sleep exactly 7 hours each night for the past 6 months,

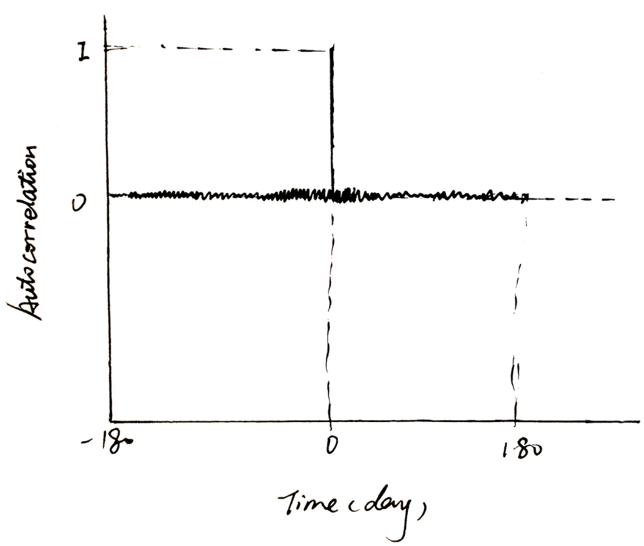
i) **[2 pts]** Sketch the sleep duration as a function of time. Label the axes of your plot.



ii) **[5 pts]** Sketch the autocorrelation of the new sleep duration data. Label the axes of your plot. Briefly explain why you think the function should look like what you sketched.
Hint: The autocorrelation should reflect the structure/periodicity of **the fluctuationsin sleep duration around its mean value**.
Because the autocorrelation reflect the fluctuation around the mean value, as the student sleeps exactly 7 hrs each night, there is no fluctuation, all the value is 0.



f) **[5 pts]** If this student were to have completely random sleep duration for the past 6 months (assume that this was physiologically possible), sketch the autocorrelation of the new sleep duration data. Label the axes of your plot. Briefly explain why you think thefunction should look like what you sketched.
Random sleep duration only correlate with itself, thus has strong peak at lag = 0, and very small value at non-value lags.



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2. **[Total: 36 pts]** A research team investigated whether pain caused systemic autonomic responses (pain causes changes to the entire body) or just the local responses (pain onlycauses changes near the pain site). They setup an experiment where quasi-random heat pain pulses were applied on the right forearm (exposed area of 3x3 mm2). When pain is perceived, the sympathetic nervous system (one branch of the autonomic nervous system) is activated and this causes changes in peripheral blood flow.

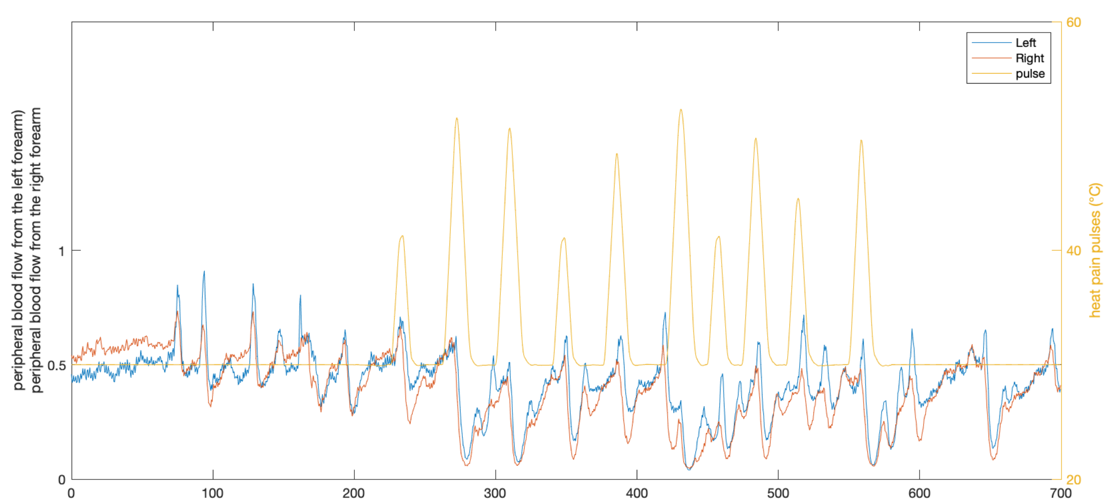
   The idea behind this experimental design is that if pain causes systemic autonomic responses, one should observe the changes in peripheral blood flow response, from both arms, that somewhat follow the quasi-random pain pulse pattern. The quasi-random input pattern (random pain pulse magnitudes and spacings) was chosen to make this pain pattern unique as it is difficult for any spontaneous fluctuations peripheral blood flow response to match well with some random pattern. So, if the quasi-random pattern appears in the peripheral bloodflow response on both arms, they can conclude that pain elicits a systemic autonomic response rather than only a local response.

   In addition, the research team wanted to investigate whether the heat pain causes vasodilation (which results in an increase in peripheral blood flow) or vasoconstriction (which results in a decrease in peripheral blood flow), and whether both left and right arms will have similar directional response.

   The data collected during the experiment are in `pain.mat`. The file contains
   - `therm` = heat pain pulses (°C)
   - `pu_right` = peripheral blood flow measured from the right forearm (perfusion unit, PU)
   - `pu_left` = peripheral blood flow measured from the left forearm (perfusion unit, PU)
   - `fs` = sampling frequency (Hz)

   The first heat pain pulse was given around 220 seconds into the recording. There was nopain given prior to 220 seconds. The subject receive a total of 10 heat pain pulses.

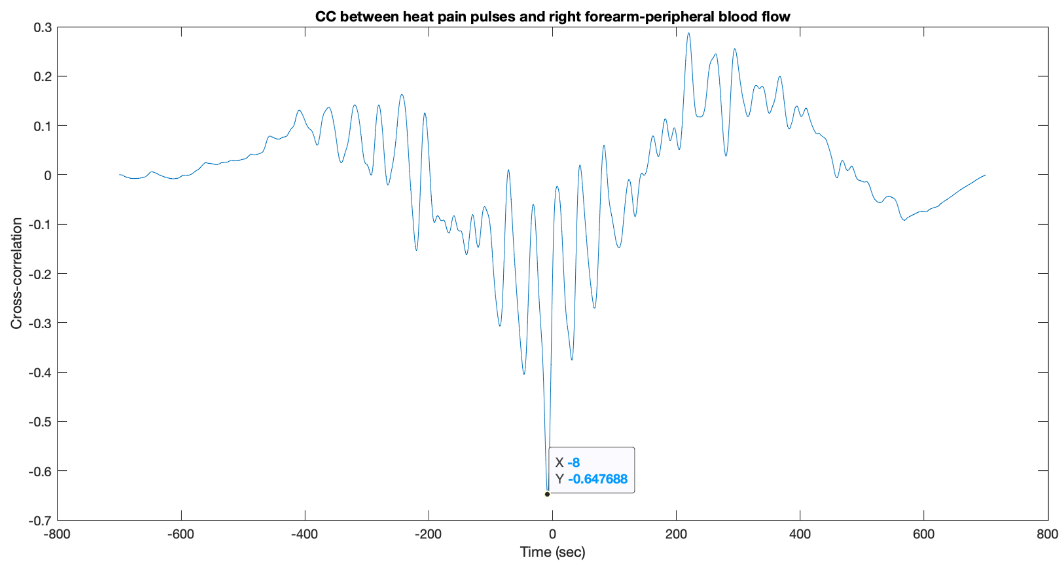
   a) **[6 pts]** Use MATLAB to plot therm, pu_right and pu_left against time <u>in seconds, starting from 0 second</u>. Label all axes.



b) Use cross-correlation to determine whether the heat pain pulse pattern exists in the peripheral blood flow measured from **right forearm**. Use `xcorr()` function in MATLAB with `'coeff'` normalization option (such that the cross-correlation function values should range between -1 and +1).

Hint: We want to investigate whether the pattern of **fluctuations around the mean value** in the pain signal exists in the **fluctuations around the mean value** in the peripheral bloodflow signal.

i) **[3 pts]** Use MATLAB to compute and plot the cross-correlation between heat pain pulses and peripheral blood flow measured from the right forearm. Display the lag (x- axis of the cross-correlation) in seconds.



ii) **[2 pts]** Indicate on the plot (e.g. using the cursor tool in MATLAB) where the two signals are maximally correlated, i.e. where the peak of the cross-correlation occurs. Report the corresponding correlation coefficient.

The two negatively related signal is heat pain signal & +8 sec right peripheral blood flow change (blood flow lags pain by 8 seconds). Corresponding correlation coefficient is -0.7677.

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iii) **[3 pts]** Did the heat pain pulses and peripheral blood flow on the right forearm change in the same or opposite direction? Briefly explain your answer.

In the opposite direction. The correlation coefficient is negative. Pain pulse and peripheral blood flow move in the opposite direction when they are maximally correlated.

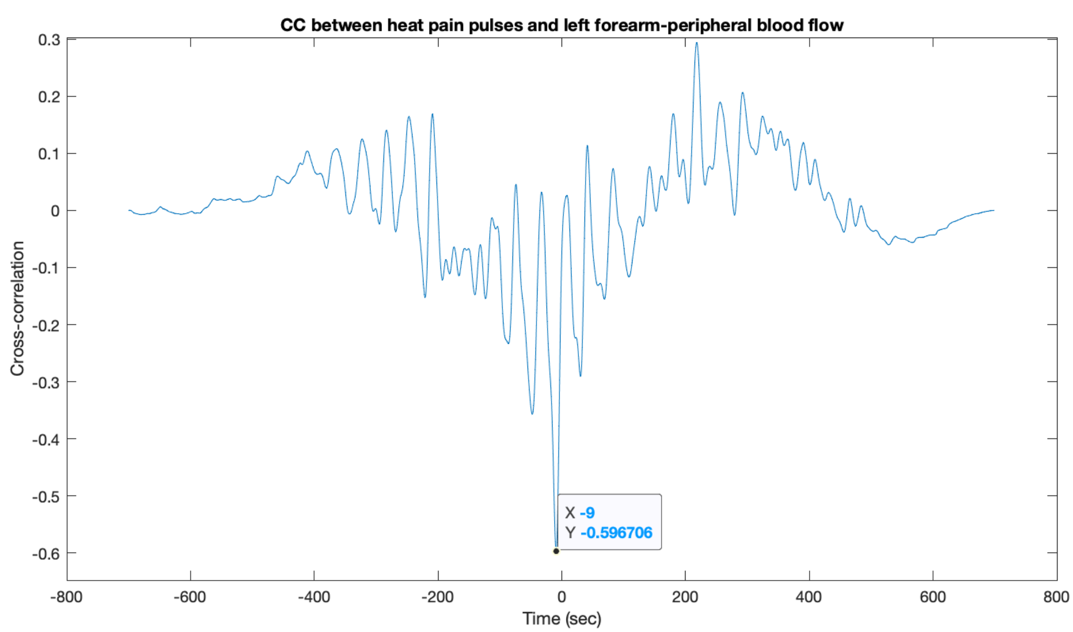
iv) **[2 pts]** How long did it take (in seconds) for the pain pulse to illicit changes in peripheral blood flow on the right forearm?

8 seconds.

c) Use cross-correlation to determine whether the heat pain pulse pattern exists in the peripheral blood flow measured from **left forearm**. Use `xcorr()` function in MATLAB with `'coeff'` normalization option (such that the cross-correlation function values should range between -1 and +1).

Hint: We want to investigate whether the pattern of **fluctuations around the mean value** in the pain signal exists in the **fluctuations around the mean value** in the peripheral bloodflow signal.

i) **[3 pts]** Use MATLAB to compute and plot the cross-correlation between heat pain pulses and peripheral blood flow measured from the left forearm. Display the lag (x-axis of the cross-correlation) in seconds.



ii) **[2 pts]** Indicate on the plot (e.g. using the cursor tool in MATLAB) where the two signals are maximally correlated, i.e. where the peak of the cross-correlation occurs. Report the corresponding correlation coefficient.

The two negatively related signal is heat pain signal & +9 sec left peripheral blood flow change (blood flow lags pain by 9 seconds). Corresponding correlation coefficient is -0.5967.

iii) **[2 pts]** How long did it take (in seconds) for the pain pulse to illicit changes in peripheral blood flow on the left forearm?

9 seconds

d) **[5 pts]** Based on your cross-correlation analysis, did pain cause systemic or local response? Explain your answer.

As we observed the change in peripheral blood flow response, the pain cause systemic response.

e) **[5 pts]** Based on your cross-correlation analysis, did pain cause vasodilation or vasoconstriction? Did the response to pain differ in direction between two arms (e.g. vasodilation in one arm and vasoconstriction in another)? Explain your answer.

Yes. The maximum correlated coefficients are negative in both arms, thus pain causes vasoconstriction in both two arms, and the response does not differ in direction.

MATLAB code

```
% % Q1 a)
load('sleep.mat')
x = (1:1:180);
scatter(x,sleephours, 24);
xlim([1, 180])
xlabel('Time(day)')
ylabel('Sleep Duration(hr)')

% % Q1 b)
ave_sleep = roundn(sum(sleephours)/180, -2);
c = xcorr(sleephours-ave_sleep,'coeff');
plot(x, c(180:end,1));
xlim([1, 180])
xlabel('Time(day)')
ylabel('Sleep Duration Autocorrelation')

% Q1 e) sleep exactly 7 hours
t_fix = ones(180,1)*7;
plot(x, t_fix);
[c_fix, lag_fix] = xcorr(t_fix-7,'coeff');
plot(x, c_fix(180:end,1));
xlim([1, 180]);
ylim([-1, 1]);
legend('Correlation');
xlabel('Time(day)')
ylabel('Fixed Sleep Duration Autocorrelation')



% % Q2 a)
load('pain.mat')
sec = (0:0.5:699.5);
[AX,H1,H2]=plotyy([sec',sec'],[pu_left,pu_right],sec',therm);
set(AX,'Xlim',[0,700])
```

```
set(AX(1),'Ylim',[0, 2])

set(AX(2),'Ylim',[20, 60])

set(get(AX(1),'Ylabel'),'string',{'peripheral blood flow from the
left forearm)';'peripheral blood flow from the right forearm'});

set(get(AX(2),'Ylabel'),'string','heat pain pulses (°C)');

xlabel({'Time (sec)'});

legend([H1(1),H1(2),H2],'Left','Right','pulse');


% Q2 b) i, ii

[c_pur, lag_pur]= xcorr(therm-(sum(therm)/1400), pu_right-
(sum(pu_right)/1400), 'coeff');

time = lag_pur/fs;

plot(time, c_pur);

xlabel('Time (sec)');

ylabel('Cross-correlation');

title('CC between heat pain pulses and right forearm-peripheral
blood flow');

[pri, mri] = min(c_pur);

[prx, mrx] = max(c_pur);


[c_pul, lag_pul] = xcorr(therm-(sum(therm)/1400), pu_left-
(sum(pu_left)/1400), 'coeff');

time = lag_pul/fs;

plot(time, c_pul);

ylim([-0.65 0.3]);

xlabel('Time (sec)');

ylabel('Cross-correlation');

title('CC between heat pain pulses and left forearm-peripheral
blood flow');

[pli, mli] = min(c_pul);

[plx, mlx] = max(c_pul);
```