Analysis of kick

November 4, 2022

1 General information

- Author: Joris Busink, Junior Teacher Physics Education.
- Date: Fri, 4th Nov.
- About: Data processing script for high-speed camera.

1.1 Load packages

I load the following packages: numpy, matplotlib.pyplot, pandas. These pacakges are always usefull in doing nummerical calculations using Python.

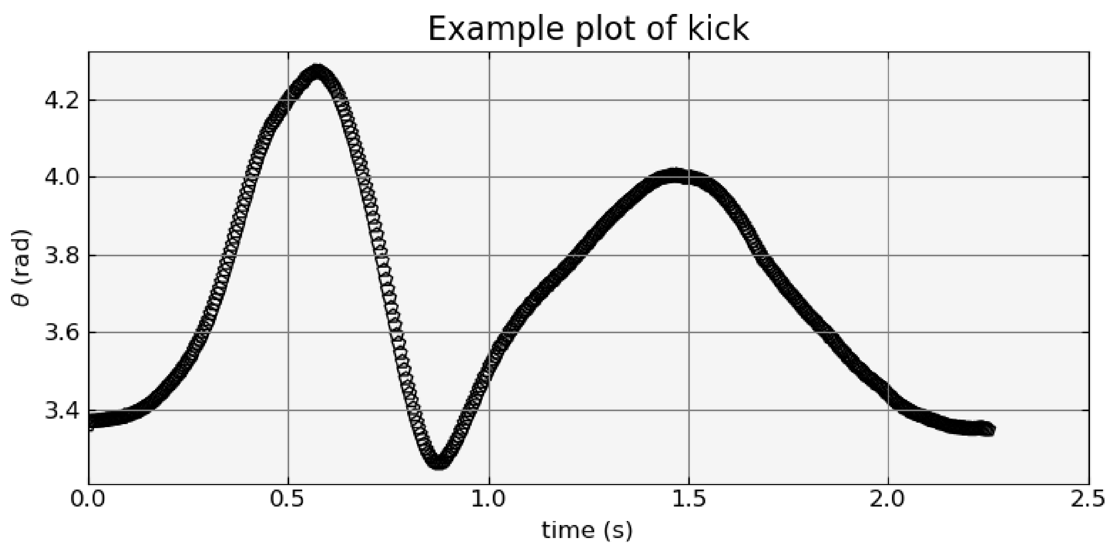
[ ]:
```
# %matplotlib widget #requires package ipympl installed, for interactive plots.
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import os
from scipy.signal import savgol_filter

from scipy.optimize import curve_fit
np.set_printoptions(precision=4,threshold =9,suppress=True)  #Compact display␣
 ↪of arrays.

cwd = os.getcwd() #get current working directory.
cwd= os.path.split(os.getcwd())[0]
```

2 Data Kick

In the previous example, we had an analytical model. However, in most (bio)mechanical experiments, there's not an analytical model that describes the process of interest. In the next sections I will (quickly) go over the data of a kick. The data was, just as before, captures with a high-speed camera.

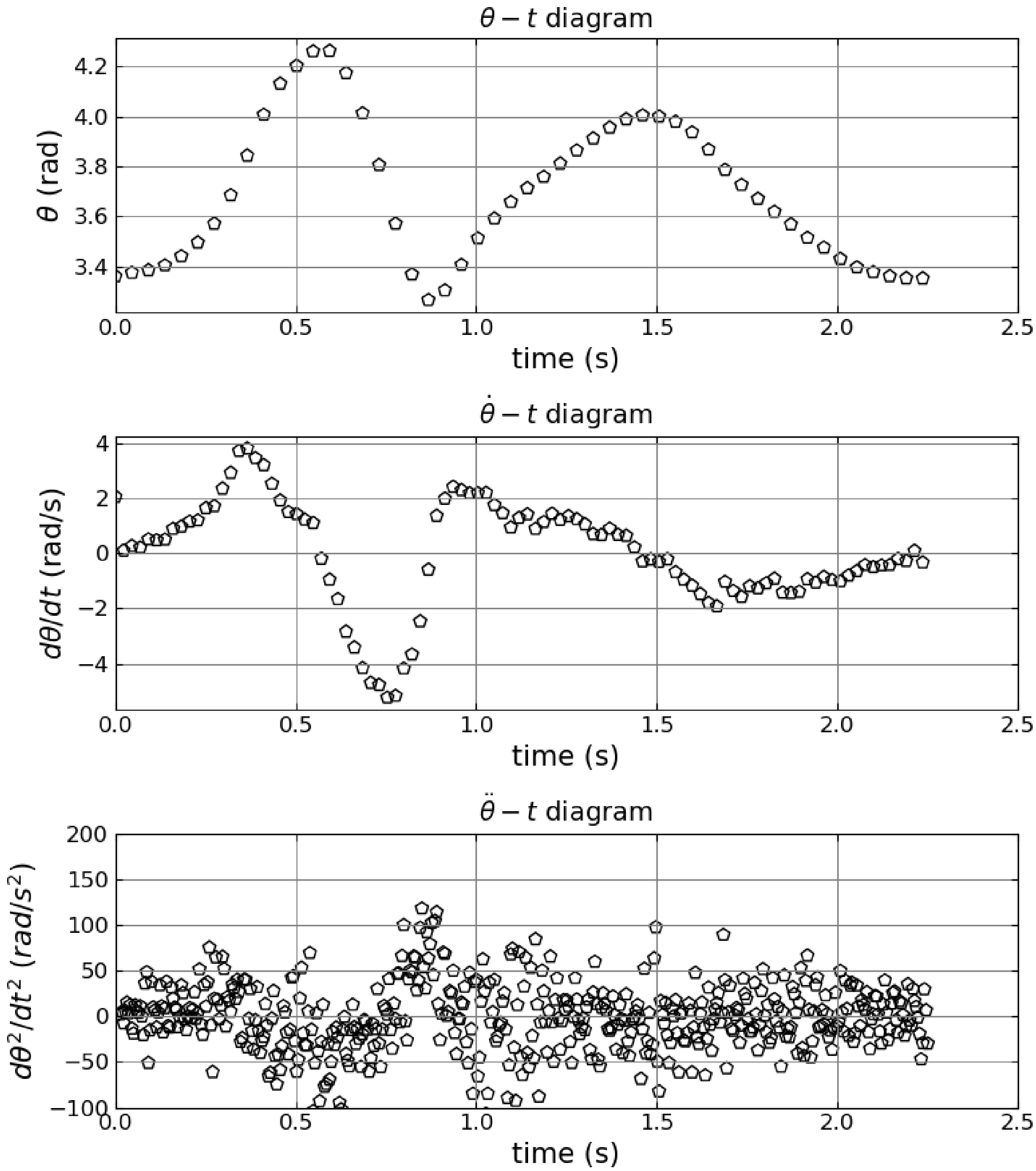
[ ]:
```
df=pd.read_csv(cwd+'/data/schop.csv', sep='\t',header=0)
Time = df['Time'].str.replace(',', '.').astype(float).to_list()
Angle = df['Angle #1'].str.replace(',', '.').astype(float).to_list()
Angle =np.asarray(Angle)*np.pi/180
```

```
[ ]: fig,axes=plt.subplots(1,1,figsize=(8,4))
axes.set_title('Example plot of kick',fontsize=16)
axes.scatter(Time,Angle ,color = 'black', s = 50, marker␣
  ↪='p',ec='black',fc='none') #plot every tenth datapoint [::10]
axes.set_xlabel('time (s)',fontsize=12)
axes.set_ylabel(r'$\theta$ (rad)',fontsize=12)
axes.set_xlim(0,2.5)
axes.tick_params(direction="in",labelsize=12,bottom = True,top = True,left=␣
  ↪True,right=True) #inward direction of tick-lines
axes.set_facecolor('whitesmoke')
axes.grid(True,color='gray')
plt.tight_layout() #creates optimal padding levels for figure (especially␣
  ↪usefull for side-by-side figures)
plt.show()
```




```
[ ]: der1 = np.gradient(Angle,Time)
der2 = np.gradient(der1,Time)

fig,axes=plt.subplots(3,1,figsize=(8,9))
axes[0].scatter(Time[::10],Angle[::10],color = 'black', s = 50, marker␣
  ↪='p',ec='black',fc='none') #plot every tenth datapoint [::10]
axes[1].scatter(Time[::5], der1[::5], color='black' , s = 50, marker␣
  ↪='p',ec='black',fc='none')
axes[2].scatter(Time[::], der2[::], color='black', s = 50, marker␣
  ↪='p',ec='black',fc='none')



axes[0].set_title(r'$\theta-t$ diagram',fontsize=14)
```

```python
axes[1].set_title(r'$\dot{\theta}-t$ diagram',fontsize=14)
axes[2].set_title(r'$\ddot{\theta}-t$ diagram',fontsize=14)
axes[2].set_ylim(-100,200)
for i in range(3):
    axes[i].set_xlim(0,2.5)
    axes[i].set_xlabel('time (s)',fontsize=15)
    axes[i].tick_params(direction="in",labelsize=12,bottom = True,top = True,left= True,right=True) #inward direction of tick-lines
    axes[i].grid(True,color='gray')

axes[0].set_ylabel(r'$\theta$ (rad)',fontsize=15)
axes[1].set_ylabel(r'$d\theta/dt$ (rad/s)',fontsize=15)
axes[2].set_ylabel(r'$d\theta^2/dt^2$ $(rad/s^2)$',fontsize=15)
plt.tight_layout()
plt.show()

# location='user_defined_location'
# plt.savefig('location'+'simple_pendulum.svg')
```

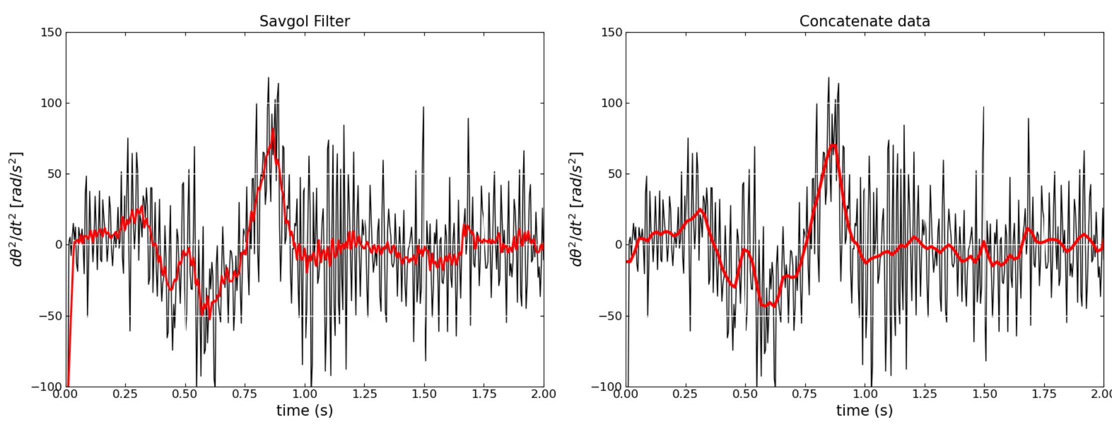


2.1 Filtered data Kick

Just as before, we apply a filter to the data. However, we cannot use the same filtering window (w). During the analysis, the filtering window has to be checked manually. The optimal window width is always a trade-off between the resolution of the data and the details of the analysis. To make this analysis a little less subjective, one can lay the filtered data on top of the original data.

[ ]:
```
x_opt = Angle[::4]
t_opt = Time[::4]
```

```
der_slice1 = np.gradient(x_opt,t_opt)
der_slice2 = np.gradient(der_slice1,t_opt)

fig,axes=plt.subplots(1,2,figsize=(16,6))
axes[0].plot(Time, der2,color = 'black',lw=1,zorder=1)
axes[0].plot(Time, savgol_filter(der2,11,1),color = 'red',lw=2,zorder=2)
axes[0].set_title('Savgol Filter',fontsize=15)

axes[1].plot(t_opt,der_slice2,color ='red',lw=3,zorder=2)
axes[1].plot(Time, der2,color = 'black',lw=1,zorder=1)
axes[1].set_title('Concatenate data',fontsize=15)

for i in range(2):
    axes[i].set_ylim(-100,150)
    axes[i].set_xlim(0,2)
    axes[i].set_xlabel('time (s)',fontsize=15)
    axes[i].tick_params(direction="in",labelsize=12,bottom = True,top =␣
 ↪True,left= True,right=True)
    axes[i].set_ylabel(r'$d\theta^2/dt^2$ $[rad/s^2]$',fontsize=15)
    axes[i].grid(True,color='white')


plt.tight_layout()
plt.show()
```



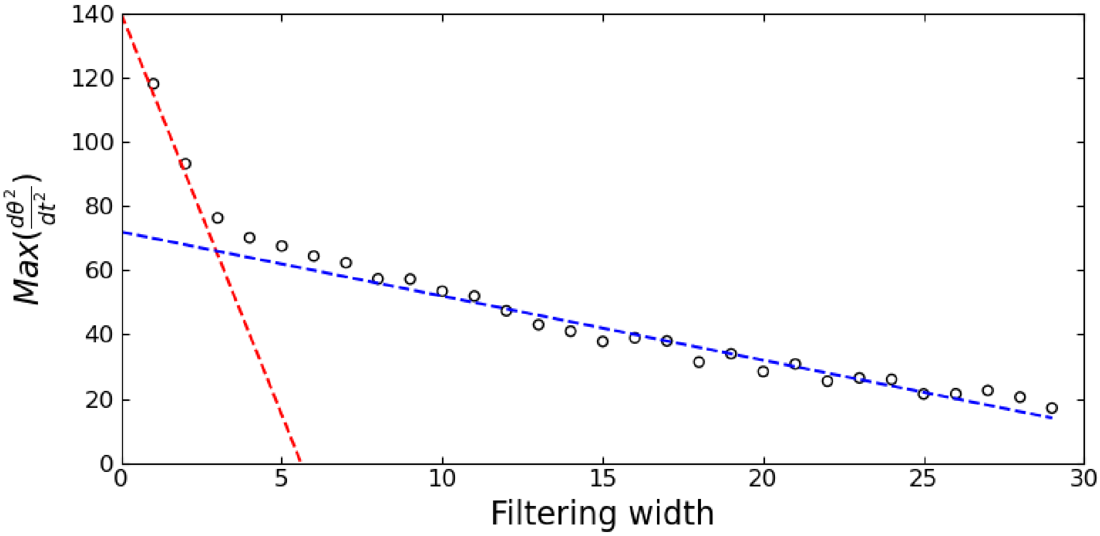
3 Optimal Filtering

In the previous two figures we observe the same trend, by adjusting the filtering the noisy data becomes more smooth. We could ask ourself the question: “What is the optimal amout of filtering?”. This is a perfectly valid question, however, it is not really! hard to answer since we don’t have an exact model. This depends on the system that you’re investigating and the question that you want to answer.

In the example of the kick, we are interested in the maximum (angular) acceleration ($\frac{d\theta^2}{dt^2}$). By increasing the strenght of the filtering we remove excessive noise. However, if we are not careful, we can also remove the signal. In the figure below I show this cross-over behaviour by calculating the maximum acceleration versus the filtering strenght.

The red-dashed line shows the removal of the noise from the data, the maximum acceleration is strongly affected by the filtering width. However, after the noise is filtered, the maximum acceleration decreases slowly, this is the removal of the signal.

[ ]:
```
windowlist = []
maxlist = []
for i in range(1,30,1):
    x_opt = Angle[::i]
    t_opt = Time[::i]
    der_slice1 = np.gradient(x_opt,t_opt)
    der_slice2 = np.gradient(der_slice1,t_opt)
    windowlist.append(i)
    maxlist.append(np.max(der_slice2))

fig,axes=plt.subplots(1,1,figsize=(8,4),sharex=True,sharey=True)

axes.scatter(windowlist,maxlist,color='black',s=25,fc='none',ec='black')
axes.plot(np.arange(0,15),140-25*np.arange(0,15),color='red',ls='--')
axes.plot(np.arange(0,30),72-2*np.arange(0,30),color='blue',ls='--')

axes.set_xlabel('Filtering width',fontsize=16)
axes.set_ylabel(r'$Max(\frac{d\theta^2}{dt^2})$',fontsize=16)
axes.set_xlim(0,30)
axes.set_ylim(0,140)

axes.tick_params(direction="in",labelsize=12,bottom = True,top = True,left=
 ↪True,right=True)
plt.tight_layout()
plt.show()
```



140
120
100
80
60
40
20
0
$Max(\frac{d\theta^2}{dt^2})$
0
5
10
15
20
25
30
Filtering width