Pulse arrival time uncertainty propagation

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This code was developed by Miodrag Bolic for the book PERVASIVE CARDIAC AND RESPIRATORY MONITORING DEVICES.

Acknowledgements:

Uncertainty propagations is based on the code: Joe Klebba (2021). Uncertainty Propagation Functions (https://www.mathworks.com/matlabcentral/fileexchange/89812-uncertainty-propagation-functions), MATLAB Central File Exchange. Retrieved May 19, 2021

```
% Changing the path from main_folder to a particular chapter
main_path=fileparts(which('Main_Content.mlx'));
if ~isempty(main_path)
    %addpath(append(main_path,'/Chapter2'))
    cd (append(main_path,'/Chapter8/PATUncertainty'))
    addpath(append(main_path,'/Service'))
end
SAVE_FLAG=0; % saving the figures in a file
```

Fitting PAT vs systolic data

Fitting is done based on regression SBP=a*ln(PAT)+b

Let us assume that the physiological signals used to obtain PAT values are sampled at 250 Hz which means that the sampling period is 4 ms. We will present the error in timing using uniform distribution in the range from -0.002s to 0.002s.

```
close all
clear_all_but('SAVE_FLAG')
fprintf('\nExample: PAT\n')
```

```
Example: PAT
```

```
load('patsbp.mat')

fo = fitoptions('Method','NonlinearLeastSquares',...
               'Lower',[-100,0],...
               'Upper',[-80,inf],...
               'StartPoint',[-90 18]);
linearfittype = fittype({'log(x)','1'},'options',fo);
fit_res = fit(patsbp.PAT,patsbp.SBP,linearfittype)
```

```
fit_res =
     Linear model:
     fit_res(x) = a*log(x) + b
     Coefficients (with 95% confidence bounds):
       a =      -95.74  (-111.3, -80.2)
       b =        17.7  (2.168, 33.23)
```

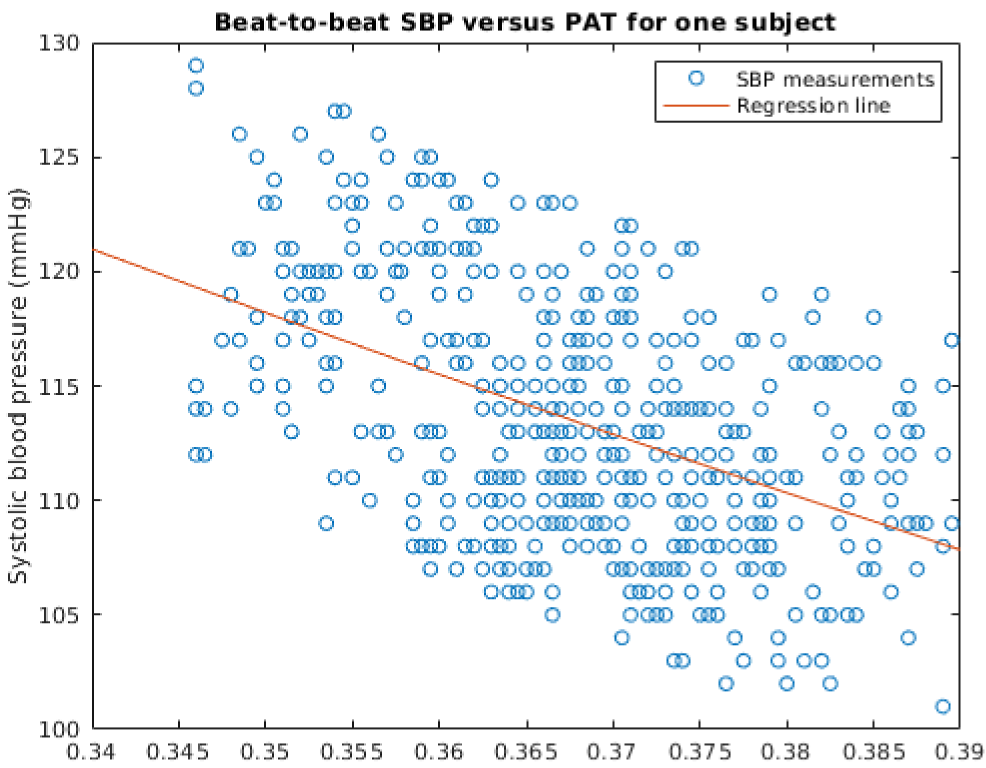
```
ci = confint(fit_res,0.67);
std_a=abs(ci(1,1)-fit_res.a) % obtain standard deviation for parameter a
```

```
std_a = 7.7091
```

```
std_b=abs(ci(2,2)-fit_res.b) % obtain standard deviation for parameter b
```

```
std_b = 7.7073
```

```

figure
plot(patsbp.PAT,patsbp.SBP,'o')
xlabel("PAT (s)")
ylabel("Systolic blood pressure (mmHg)")
hold on
i=0.34:0.01:0.39;
plot(i,fit_res(i))
legend({'SBP measurements', 'Regression line'})
title('Beat-to-beat SBP versus PAT for one subject')
annonation_save('a)',"Fig8.6a.jpg", SAVE_FLAG);
```



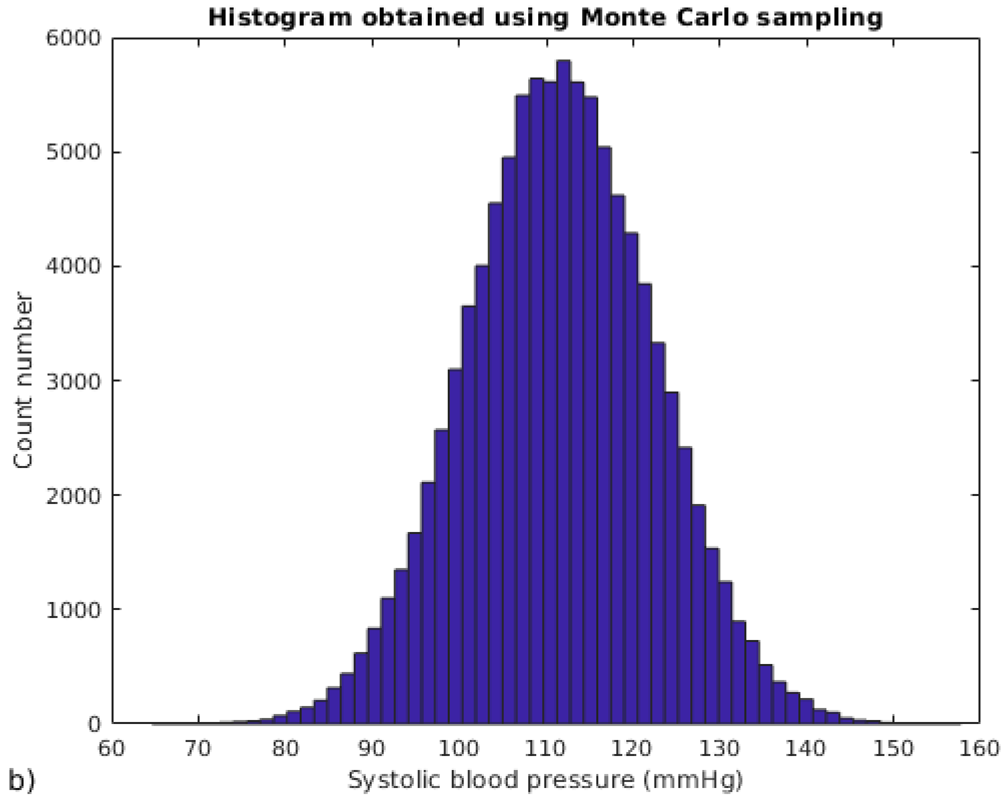
a)

Defining the uncertainties of the parameters

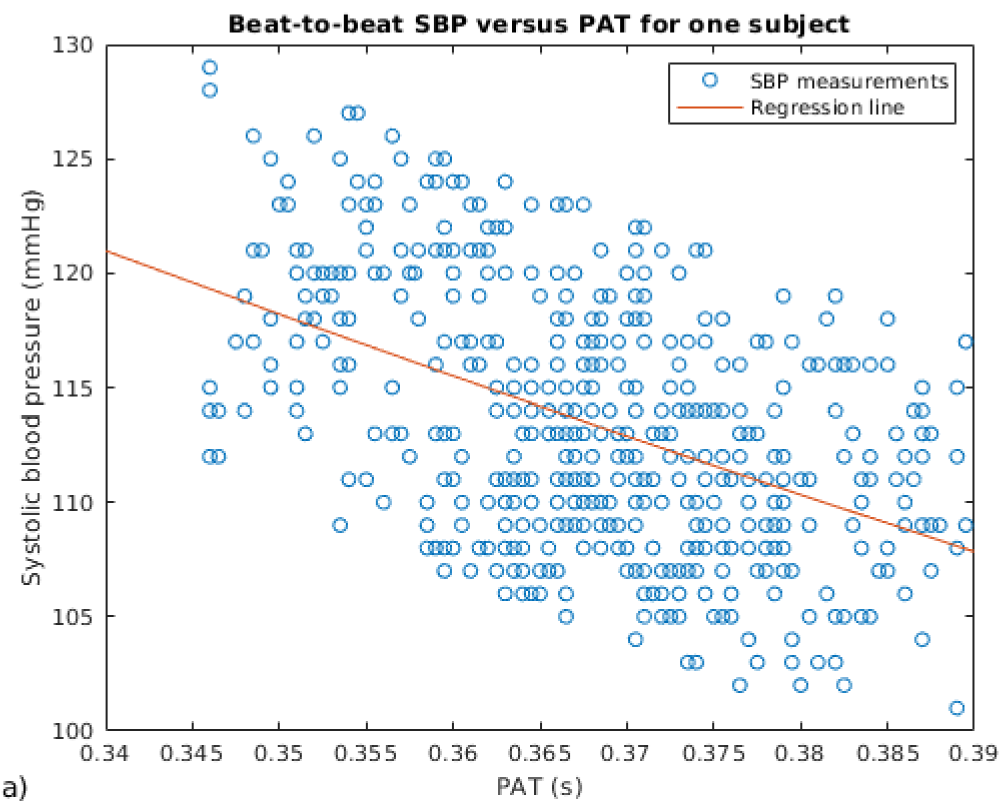
```
PAT=0.375;
b=fit_res.b; ub=std_b; % these values are obtained after fitting
a=fit_res.a; ua=std_a; % these values are obtained after fitting
f = @(a,b,x)a.*log(x)+b;
n=100000;
    PAT_data=PAT*ones(n,1)+unifrnd(-0.002,0.002,n,1)-unifrnd(-0.002,0.002,n,1);
```

Performing uncertainty propagation

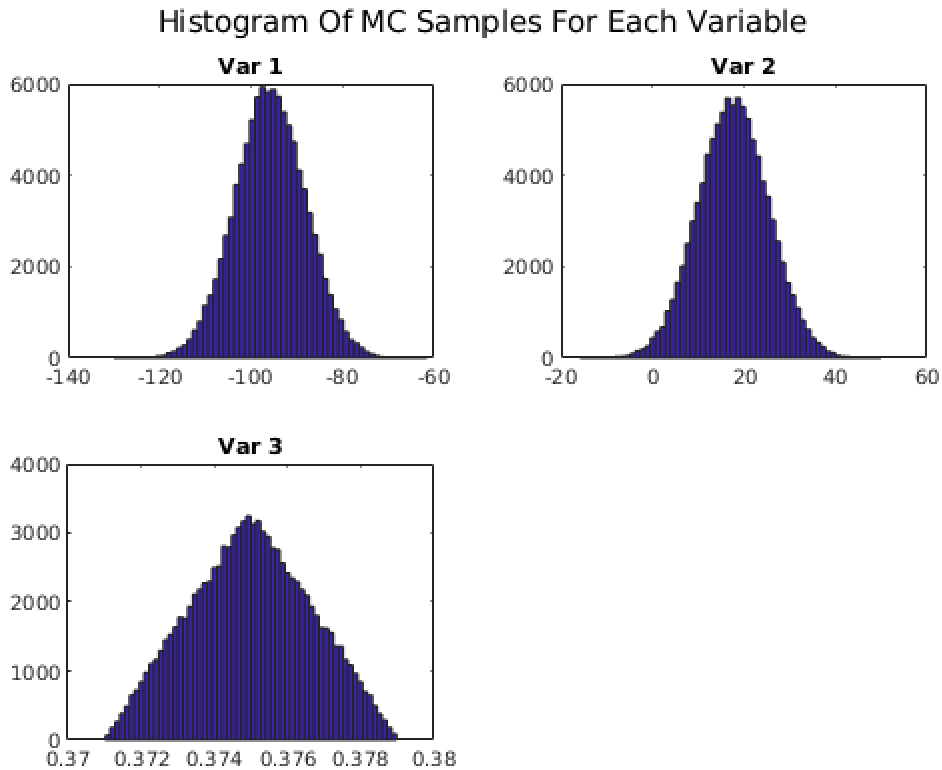
```
[CI,valMC]=propUncertMC(f,{{a ua};{b,ub};{'Custom',PAT_data}},n,'mean','varHist',60,'hi
ylabel("Count number")
xlabel("Systolic blood pressure (mmHg)")

title('Histogram obtained using Monte Carlo sampling')
annonation_save('b)',"Fig8.6b.jpg", SAVE_FLAG);
```


Histogram obtained using Monte Carlo sampling
Count number
Systolic blood pressure (mmHg)
0
1000
2000
3000
4000
5000
6000
60
70
80
90
100
110
120
130
140
150
160

b)


Beat-to-beat SBP versus PAT for one subject
SBP measurements
Regression line
Systolic blood pressure (mmHg)
PAT (s)
100
105
110
115
120
125
130
0.34
0.345
0.35
0.355
0.36
0.365
0.37
0.375
0.38
0.385
0.39

a)




```
uncertMC = (CI(2)-CI(1))/2
```

```
uncertMC = 10.7214
```

```
valMC
```

```
valMC = 111.6235
```

```
% Computing 95% intervals
[CI95,valMC]=propUncertMC(f,{{a ua};{b,ub};{'Custom',PAT_data}},n,'mean','CI',0.95)
```

```
CI95 = 1×2
   90.7600  133.2719
valMC = 111.6254
```

Excersize: repeat uncertainty quantification for the case when uncertainties in estimating coefficients are negligible: ub=ua=0.0001. What is the standard deviation and 95% confidence intervals in this case.

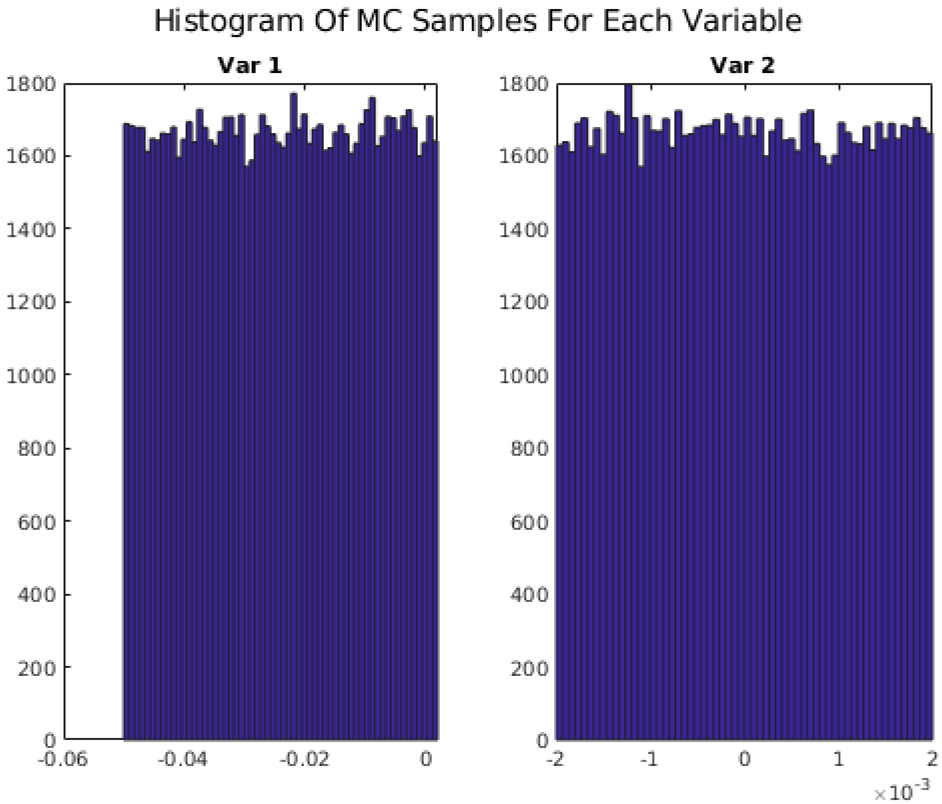
Averaging the estimated over time

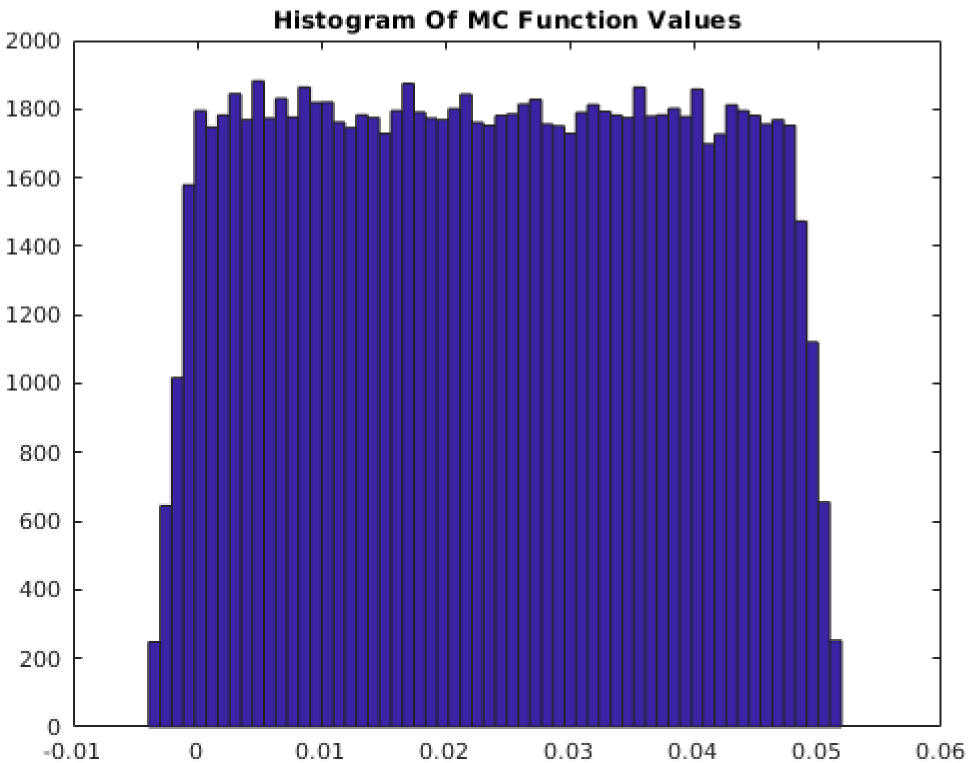
```
T=15; %averaging over T pulsees
uncertMC_T=uncertMC/sqrt(15)
```

```
uncertMC_T = 2.7682
```

Example of calculating uncertainty subtraction of two uniform random variable

```
%Now truncate the distribution to prevent complex numbers.
f1 = @(x1,x2)x2-x1;
[CI,valMC]=propUncertMC(f1,{{'uniform',-0.05,0.002};{'uniform',-0.002,0.002}},n,'mean',
```






```
uncertMC = (CI(2)-CI(1))/2  % this is a triangular distribution and therefore this way
```

```
uncertMC = 0.0176
```

```
valMC
```

```
valMC = 0.0240
```