Heart Valve Defect Diagnosis Using Pitch Estimation

Using
Comb Filter Estimator,
Autocorrelation Estimator,
and
Nonlinear Least Squares Estimator

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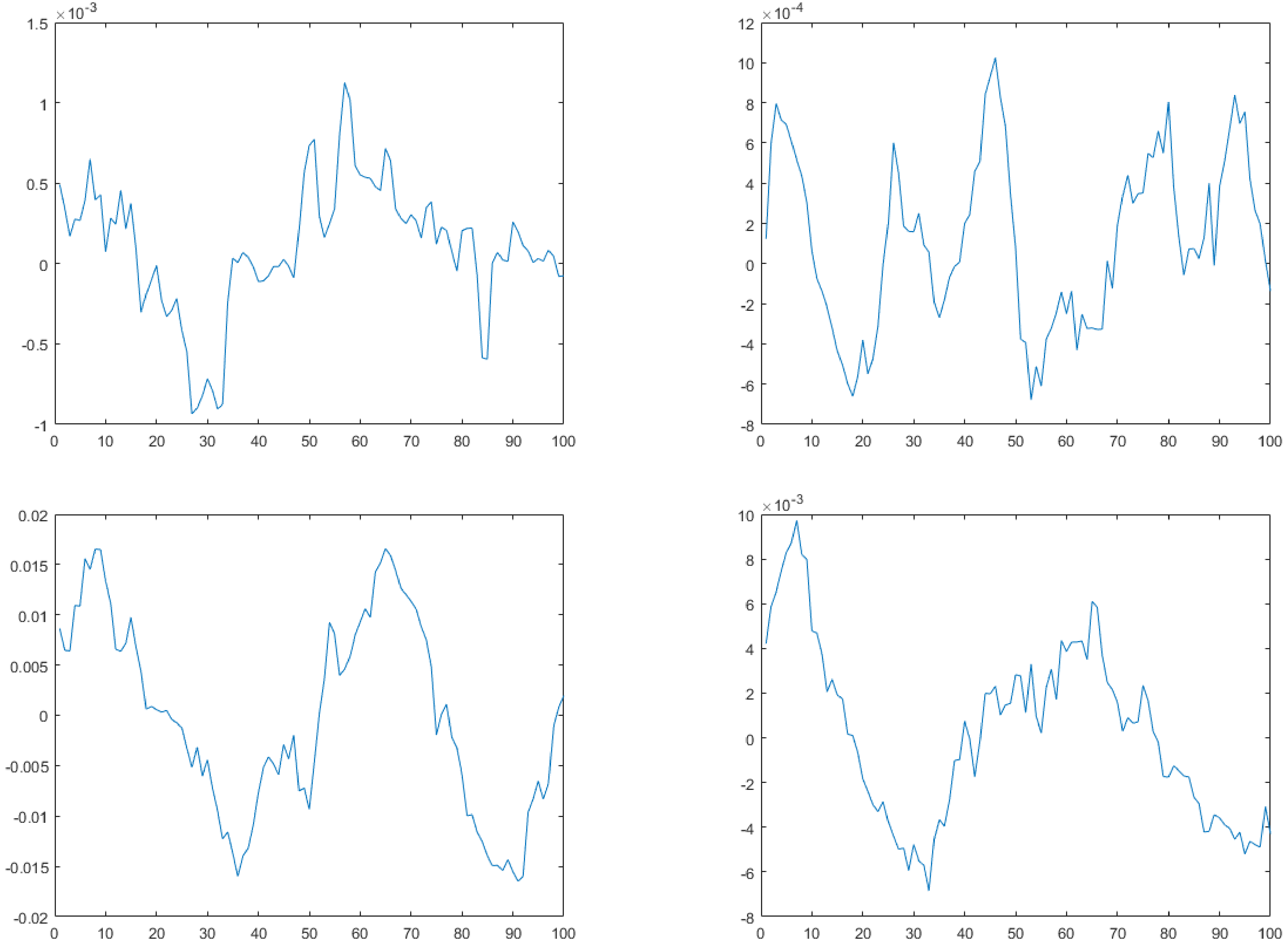
Sound and Music Signal Analysis

Agenda

- Audio Files
- Comb Filter Estimator
- Autocorrelation Estimator
- Nonlinear Least Squires Estimator
- Result

Audio Files

- Different kind of noises
- From clinical and non clinical environments
- Run through bandpass filter
  - In this study 35 Hz – 1000 Hz
- Segmented into heart states using a Hidden Duration Markov Model
  - Subsegmented into 50 ms (fs = 2000 Hz) and median segment created out from the subsegments



×10^-3
1.5
1
0.5
0
-0.5
-1
0 10 20 30 40 50 60 70 80 90 100
×10^-4
12
10
8
6
4
2
0
-2
-4
-6
-8
0 10 20 30 40 50 60 70 80 90 100
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
0 10 20 30 40 50 60 70 80 90 100
×10^-3
10
8
6
4
2
0
-2
-4
-6
-8
0 10 20 30 40 50 60 70 80 90 100

Period Signals

$$x(n) = x(n - \tau)$$

for some τ

$$\omega_0 = 2\pi/\tau$$

$$s(n) = \sum_{l=1}^{L} h_l(n) = \sum_{l=1}^{L} A_l \cos(l\omega_0 n + \phi_l)$$

$$s(n) = \sum_{l=1}^{L} [a_l \cos(l\omega_0 n) - b_l \sin(l\omega_0 n)]$$

$$= \sum_{l=1}^{L} [\cos(l\omega_0 n) \; - \sin(l\omega_0 n)] \begin{bmatrix} a_l \\ b_l \end{bmatrix}$$

where $a_l = A_l \cos(\phi_l)$ and $b_l = A_l \sin(\phi_l)$

Comb Filter Estimator

$$e(n) = x(n) - ax(n-\tau)$$

$$E(\omega) = X(\omega) - aX(\omega)\mathrm{e}^{-j\omega\tau} = X(\omega)(1 - a\mathrm{e}^{-j\omega\tau})$$

$$J(a,\tau) = \frac{1}{N-\tau}\sum_{n=\tau}^{N-1}|e(n)|^2 = \frac{1}{n-\tau}\sum_{n=\tau}^{N-1}|x(n) - ax(n-\tau)|^2$$

$$E(\omega) = X(\omega) - X(\omega)\mathrm{e}^{-j\omega\tau} = X(\omega)(1 - \mathrm{e}^{-j\omega\tau})$$

$$J(\tau) = \frac{1}{N-\tau}\sum_{n=\tau}^{N-1}|e(n)|^2 = \frac{1}{n-\tau}\sum_{n=\tau}^{N-1}|x(n) - x(n-\tau)|^2$$

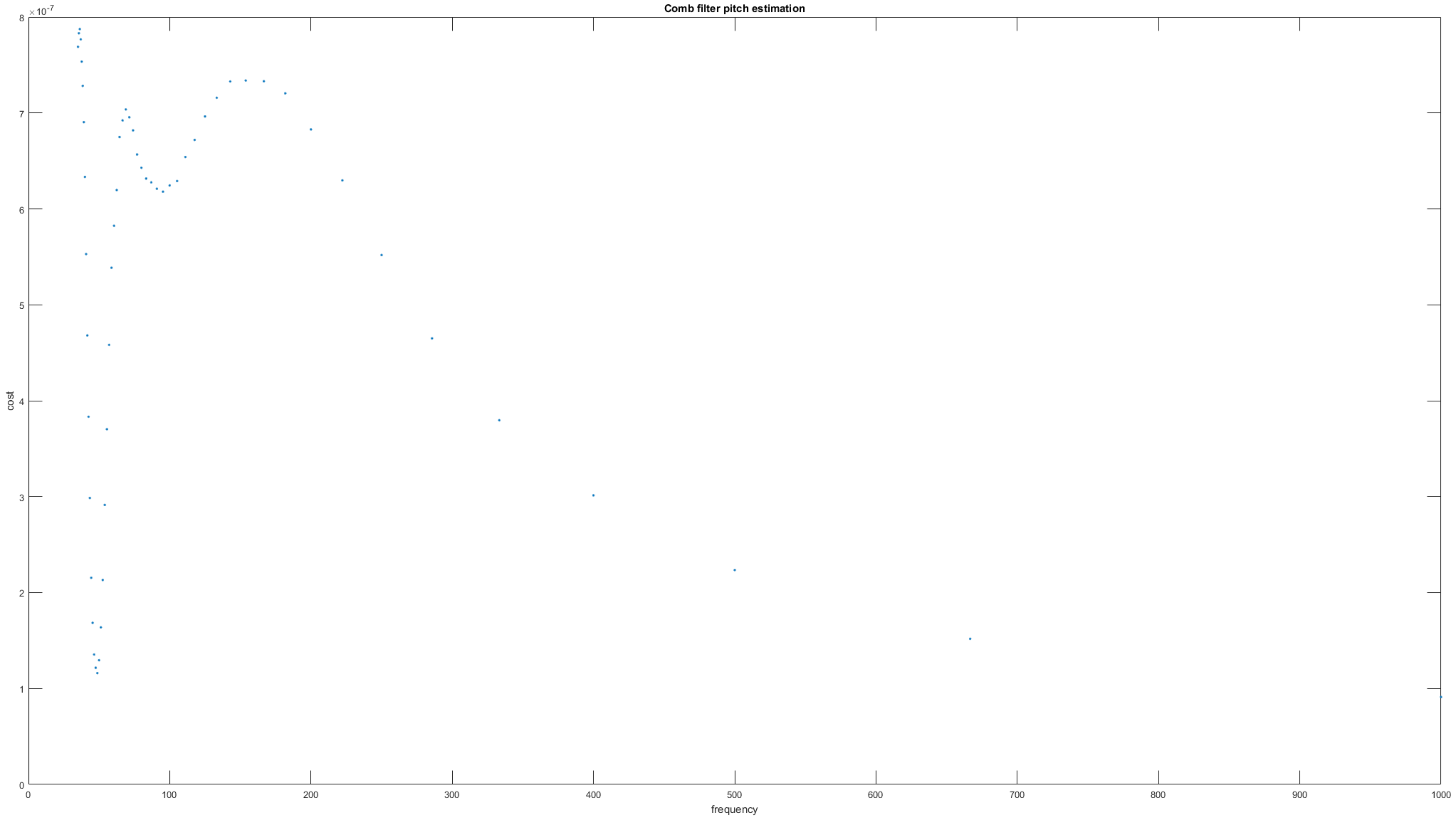
$$\hat{\tau} = \underset{\tau \in [\tau_{MIN}, \tau_{MAX}]}{\operatorname{argmin}} \; J(\tau)$$

Estimation of the â gain

$$\hat{a} = \frac{\sum_{n=\tau}^{N-1} x(n)x(n-\tau)}{\sum_{n=\tau}^{N-1} x(n-\tau)}$$

$$\hat{\tau} = \underset{\tau \in [\tau_{MIN}, \tau_{MAX}]}{\operatorname{argmin}} J(\tau) \frac{1}{n-\tau} \left[\sum_{n=\tau}^{N-1} x^2(n) - \frac{[\sum_{n=\tau}^{N-1} x(n)x(n-\tau)]^2}{\sum_{n=\tau}^{N-1} x(n-\tau)} \right]$$

Comb Filter Cost Function



Autocorrelation Estimator

$$J(\tau) = \frac{1}{N-\tau} \sum_{n=\tau}^{N-1} |e(n)|^2 = \frac{1}{n-\tau} \sum_{n=\tau}^{N-1} |x(n) - x(n-\tau)|^2$$

$$G(a,\tau) = \mathbb{E}[|e(n)|^2] = \mathbb{E}[|x(n) - ax(n-\tau)|^2]$$
$$= \mathbb{E}[|x(n)|^2] + a^2\mathbb{E}[|x(n-\tau)|^2] - 2a\mathbb{E}[x(n)x(n-\tau]$$
$$= \sigma_x^2 + a^2\sigma_x^2 - 2ar_x(\tau)$$

$r_x(\tau)$

Autocorrelation Estimator

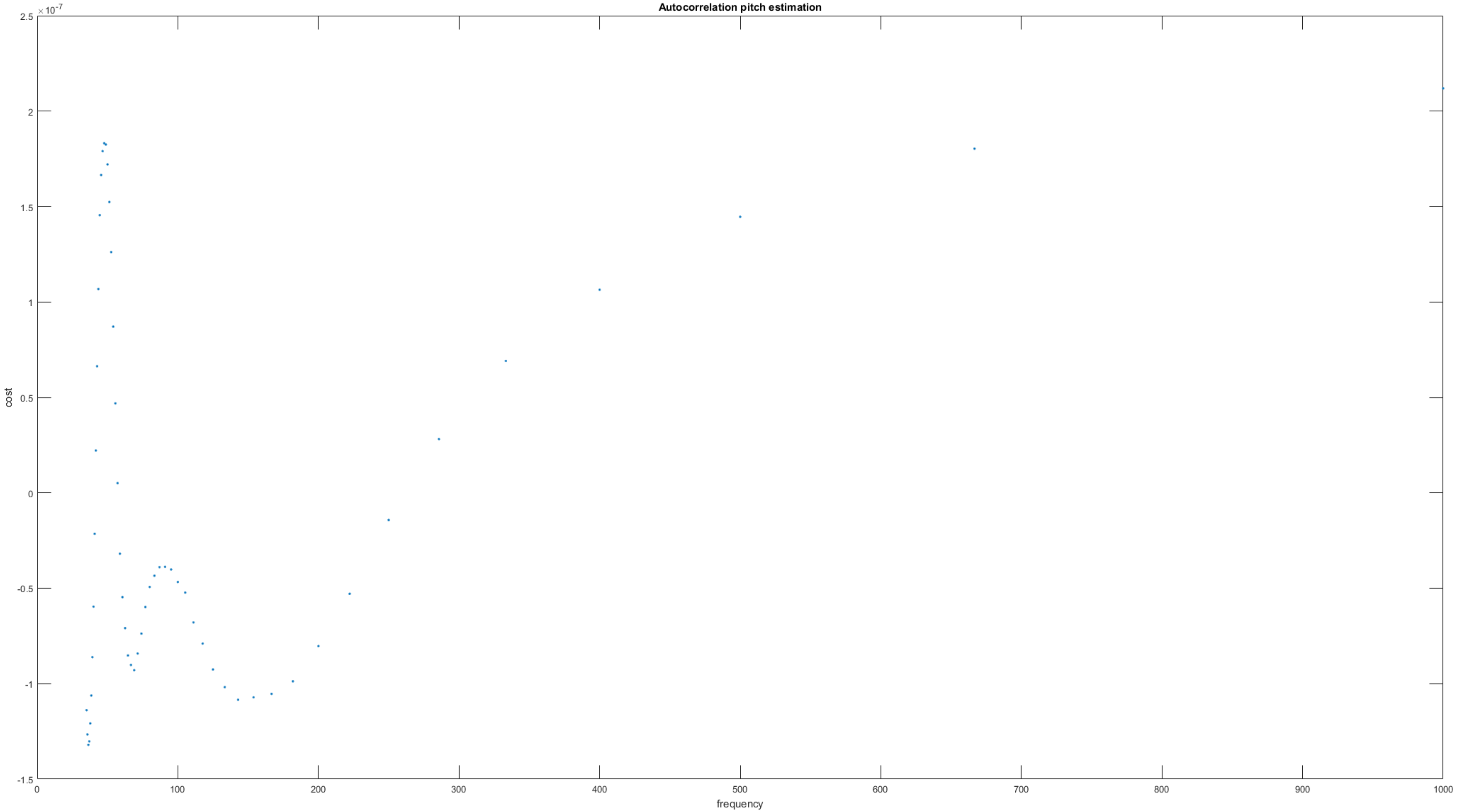
$$R(\tau) = \frac{1}{N-\tau} \sum_{n=\tau}^{N-1} x(n)x(n-\tau)$$

$$\hat{\tau} = \underset{\tau \in [\tau_{MIN}, \tau_{MAX}]}{\operatorname{argmax}} R_x(\tau)$$

Estimation of the â gain

$$\hat{\tau} = \underset{\tau \in [\tau_{MIN}, \tau_{MAX}]}{\operatorname{argmax}} J(\tau) \frac{1}{n - \tau} \left[\sum_{n=\tau}^{N-1} x^2(n) \frac{\left[\sum_{n=\tau}^{N-1} x(n) x(n-\tau)\right]^2}{\sum_{n=\tau}^{N-1} x(n-\tau)} \right]$$

Autocorrelation Cost Function



Nonlinear Least Squares (NLS) Estimator

$$s(n,\theta) = \sum_{l=1}^{L} h_l(n) = \sum_{l=1}^{L} A_l \cos(l\omega_0 n + \phi_l)$$

$$\theta = [A_1 ... A_L \phi_1 ... \phi_L \omega_0]^T$$

$$e(n) = x(n) - s(n,\theta)$$

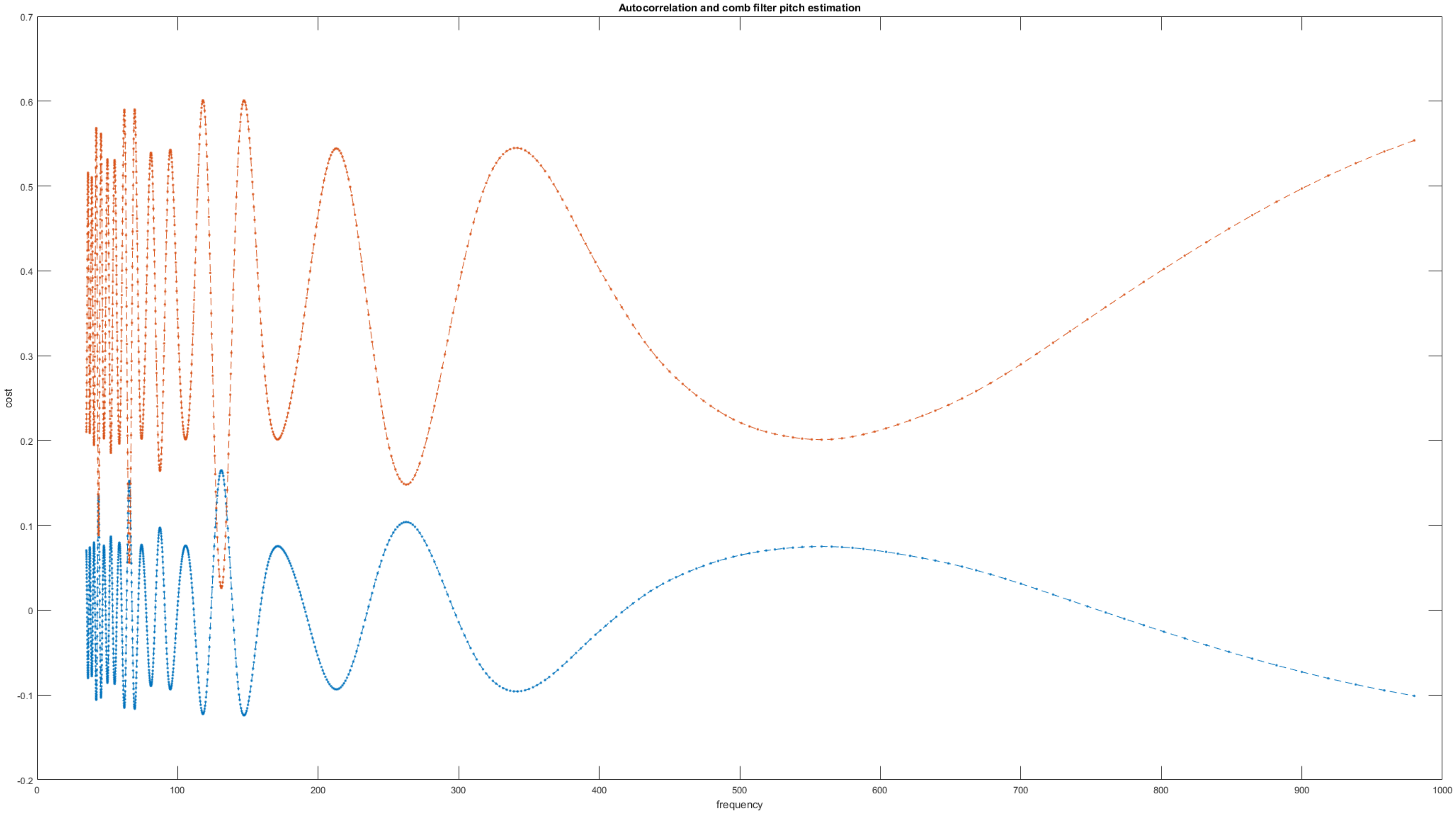
$$J_l(\theta) = \sum_{n=0}^{N-1} |e(n)|^2 = \sum_{n=0}^{N-1} |x(n) - s(n-\theta)|^2$$

$$\hat{\theta} = \underset{\theta}{\operatorname{argmin}}\, J(\theta)$$

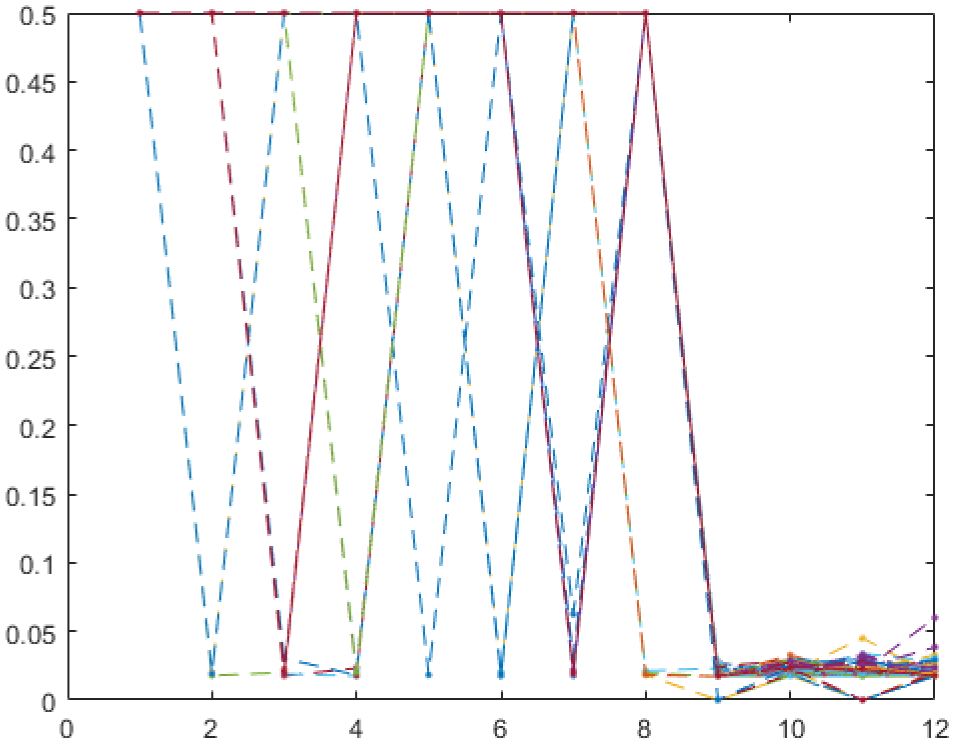
Advantages and Disadvantages

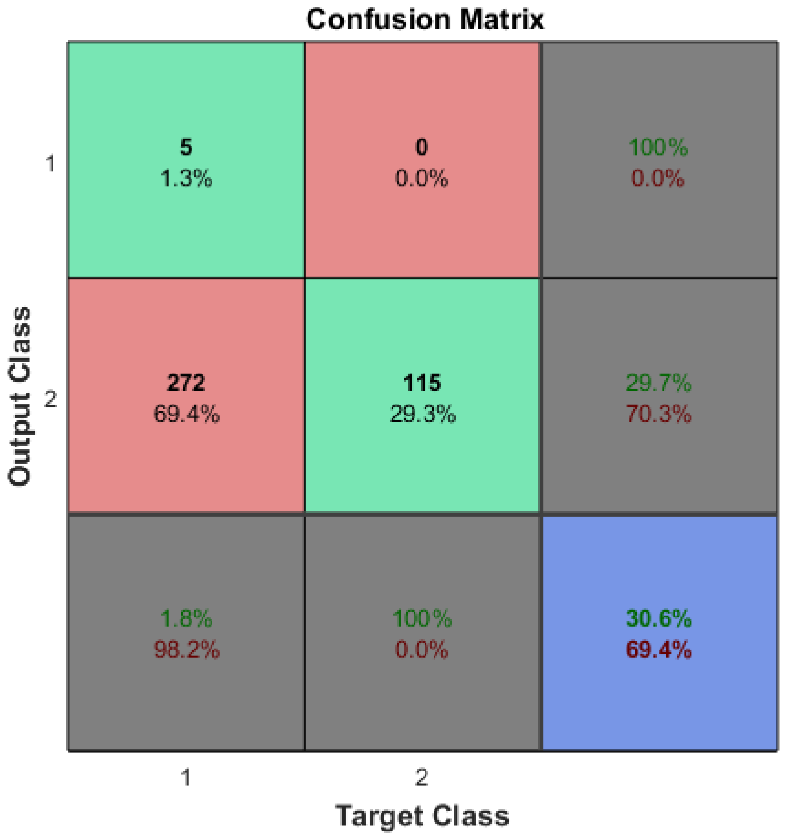
- Low computational cost
- Tau can only be estimated in integer values
- Fewer and fewer samples are used when tau increase. Tau for small fundamental frequency is big, meaning the comb filter and autocorrelation has relatively poor time-frequency resolution
- Resolution is limit by the sample grid
- Sensitive to noise

- NLS is more precise, but has a higher computational cost


Autocorrelation and comb filter pitch estimation
cost
frequency
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
100
200
300
400
500
600
700
800
900
1000

Results


0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12


Confusion Matrix
5
1.3%
0
0.0%
100%
0.0%
272
69.4%
115
29.3%
29.7%
70.3%
1.8%
98.2%
100%
0.0%
30.6%
69.4%
Output Class
1
2
Target Class
1
2

References

- Mads Græsbøll Christensen, 2016. Pitch Estimation for Dummies
- Fast Fundamental Frequency Estimation Using Least Squares – Jesper Kjær Nielsen https://www.youtube.com/watch?v=F0XgU-9ERp4&t