A novel pitch evaluation method based on a cross-correlation filter

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Abstract

A cross correlation filter – a half period of sinusoidal waveform sequence (\(p_T\) period), is applied to filter the topographical signal (\(p_T\) period) of an arbitrary grating. The cross-correlation filter can extract the signals of interest from noise. Fourier-Transform-based (FT) method can be used, but it cannot detect the pitch uniformity.

1. If present pitch evaluation methods meet noise?

2. 1D sinusoidal grating-probed signal filtering

A cross correlation filter:

\[ T(x_T) = \sum_{-\infty}^{\infty} R_k \cos \frac{2\pi x_T}{p} \]  

After cross-correlation filtering, the signal:

\[ R_k = R_{k-1} + R_{k+1} - 2R_k \]  

where \(k < \infty\) is still a tilt component.

4. Application of cross-correlation filter to signal of 1D, \(p\)-periodic and arbitrary-structured grating

It can be written as a Fourier series:

\[ f(x_T) = \sum_{n} A_n \sin \frac{2\pi x_T}{p} \]  

where \(A_n = \frac{2}{p} \int_{-p/2}^{p/2} f(x_T) \sin \frac{2\pi x_T}{p} dx_T \) (9)

when it cross-correlated with a half sinusoidal waveform template of \(p\)-period, \(R_p = C_1 \sin \frac{2\pi x_T}{p} + C_2 \sin \frac{2\pi x_T}{p} + \ldots \) (10)

where \(p = k/p, k = 2, 3, 4, \ldots \) and \(C_i \) is proportional to \(A_i\)

5. Experiments and results

5.1 Agreement between evaluated pitch and true pitch value

Table 1 Simulation results of average of pitch deviations and variations (arbitrary units)

<table>
<thead>
<tr>
<th>Pitch evaluation method</th>
<th>Noise level</th>
<th>Deviation average</th>
<th>Variation (STD)</th>
<th>Deviation average</th>
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5.2 Cross-correlation filtering and pitch evaluation in PD method

It can be written as a Fourier series:

\[ f(x_T) = \sum_{n} A_n \sin \frac{2\pi x_T}{p} \]  

where \(A_n = \frac{2}{p} \int_{-p/2}^{p/2} f(x_T) \sin \frac{2\pi x_T}{p} dx_T \) (9)

when it cross-correlated with a half sinusoidal waveform template of \(p\)-period, \(R_p = C_1 \sin \frac{2\pi x_T}{p} + C_2 \sin \frac{2\pi x_T}{p} + \ldots \) (10)

where \(p = k/p, k = 2, 3, 4, \ldots \) and \(C_i \) is proportional to \(A_i\)

5.3 In-plane tilt angles measurement

Figure 9. (a), (b) and (c) are the images of 1D sinusoidal grating with in-plane tilt angle I, II and III respectively. Angles are measured and calculated as 21.57, 35.12 and 12.03° while measurement repeatability (STD) is 0.027, 0.044 and 0.05° respectively.

References