Measurement noise evaluation, noise bandwidth specification and temperature effects in 3D point autofocusing microscopy

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Introduction
Quantifying the metrological characteristics of a point autofocus instrument is essential to establish its traceability, as such characteristics may influence the results of measurement and have direct contribution to measurement uncertainty (ISO/DIS 25178-600) [1]. In this work we evaluate the measurement noise \( \left( N_M \right) \), which is the noise added to the output signal occurring during the normal operation of the instrument. To provide proper reference for performance specification comparison, \( N_M \) is specified along with the measurement bandwidth; to complete noise evaluation, static noise \( \left( N_S \right) \) and autofocus repeatability \( \left( R_{AF} \right) \) are assessed (ISO 25178-605) [2]. This work is a first step towards establishing traceability of a PAI and assessing the influence of environmental disturbance on measurement.

Methodology
\( N_M \): Defined in ISO/DIS 25178-600. Application of average and subtraction method [3]: 15 repeated surface measurements were performed.
\( N_S \): standard deviation of the vertical stage fluctuation when lateral scanning is not performed (ISO 25178-605).
\( R_{AF} \): noise (as standard deviation) of autofocus sensor in the absence of environmental disturbance (ISO 25178-605).
\( N_S \) and \( R_{AF} \) were obtained while focusing on a single point.

Temperature effect: correlation between surface height and temperature was established to account for the influence of environmental disturbance.

Sample and settings

<table>
<thead>
<tr>
<th>Sample</th>
<th>Calibrated optical flat ( S_z ) (4±9.8) nm (NPL-BNT 019)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>MLP-3SP (Mitaka Kohki)</td>
</tr>
<tr>
<td>Objective</td>
<td>100×, AN 0.8</td>
</tr>
<tr>
<td>Measured area</td>
<td>100 µm × 100 µm</td>
</tr>
<tr>
<td>Scanning pitch</td>
<td>0.1 µm</td>
</tr>
<tr>
<td>Stepping pitch</td>
<td>1 µm</td>
</tr>
<tr>
<td>Temperature probe</td>
<td>Pt-1000 two wire (± 0.15 °C)</td>
</tr>
</tbody>
</table>

Results
- Temperature fluctuation was found to have caused drift in measured surface height.
- Temperature effect can be removed with the drift compensation routine built in the software.

\[
N_{M, \text{subtraction}} = \frac{S_{q, \Delta}^2}{\sqrt{n}}
\]

\[
N_{M, \text{average}} = \sqrt{\frac{S_{q}^2 - S_{qm}^2}{1 - 1/n}}
\]

\( N_{M, \text{subtraction}} = S_{q, \Delta} \)
\( N_{M, \text{average}} = S_{q} / \sqrt{n} \)

\( N_M = 2 \text{ nm or } 0.4 \text{ nm/Hz} \)
\( N_S = 2 \text{ nm} \)
\( R_{AF} = 5 \text{ nm} \)

Future work
To complete the characterisation of PAI, the remaining metrological characteristics (flatness deviation, amplification coefficient and linearity deviation of the three axes, \( x-y \) perpendicularity, topographic spatial resolution and maximum measurable local slope) shall be evaluated also exploiting methodologies proposed in good practice guides and draft ISO specification standards.

References

Acknowledgements
The authors would like to acknowledge funding from EPSRC grant EP/M008983/1.

Methodology

\( N_M, \text{subtraction} = \bar{S}_{q, \Delta} \)
\( N_M, \text{average} = \frac{S_{q}^2}{n} - \frac{S_{qm}^2}{n} \)

\( n = 15 \)

\( S_{q} = \sqrt{\sum_{i=1}^{n} (S_i - \bar{S})^2} \)

\( \bar{S} = \frac{1}{n} \sum_{i=1}^{n} S_i \)

\( S_{qm} = \sqrt{\sum_{i=1}^{n} (S_i - \bar{S}_m)^2} \)

\( \bar{S}_m = \frac{1}{n} \sum_{i=1}^{n} S_i \)

\( S_{q, \Delta} = \sqrt{\sum_{i=1}^{n} (S_i - \bar{S}_o)^2} \)

\( \bar{S}_o = \frac{1}{n} \sum_{i=1}^{n} S_i \)

Temperature / °C
Surface height / µm

Temperature effect: correlation between surface height and temperature was established to account for the influence of environmental disturbance.

Figure 1: Drift in measured surface topography due to temperature fluctuation.

Figure 2: Surface topography after drift compensation.

Figure 3: Correlation between surface height and chamber temperature.

Figure 4: Repeatability of the autofocus sensor \( R_{AF} \).

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