Agnostic compensation of periodic errors in interferometric position sensing

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Interferometric position sensors play a vital role in semiconductor fabrication, nanotechnology, and advanced scientific applications requiring sub-nanometer accuracy in position monitoring and control. The core operating principle of these sensors relies on the quadrature detection scheme, which enables the extraction of the interferometric phase from two phase-shifted sinusoidal signals. However, in practice, imperfections such as sensor offsets or gain imbalances often distort the resulting quadrature signals, resulting in systematic periodic errors in position sensing. While Heydemann's widely used compensation method addresses these distortions, it assumes the Lissajous figure formed by the quadrature signals is elliptic—a condition not always met in practice, particularly for interferometer designs, such as Fabry-Perot or those generating quadrature signals via laser current modulation.
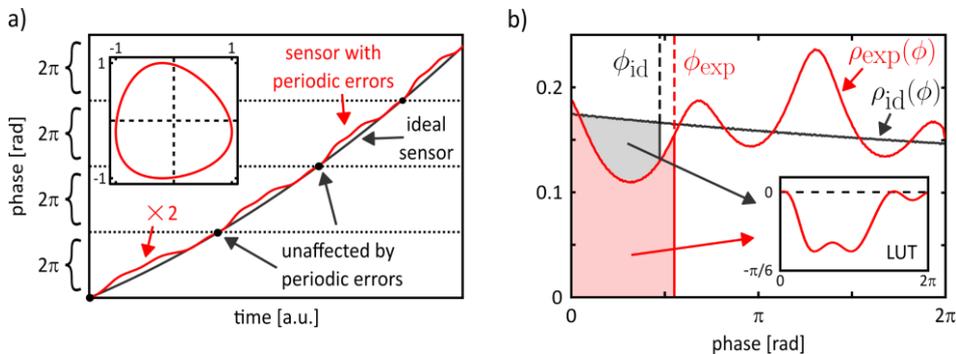

*Figure 1: **a)** A distorted Lissajous figure (inset) leads to periodic measurement errors. However, if the target motion is tracked over multiple fringes and only phase values differing by 2π are used, the correct trajectory can be estimated with high accuracy. **b)** A comparison between the experimentally observed phase angle distribution $\rho_{exp}(\phi)$ and the ideal distribution $\rho_{id}(\phi)$ enables the derivation of a compensation lookup table (LUT). Specifically, this involves calculating the cumulative sums of both distributions.*

In this work, we present a novel compensation algorithm that does not rely on the assumption of an elliptic Lissajous figure. Instead, it requires only that measurement errors be periodic, the target motion follow a smooth trajectory consistent with physical laws, and that the data be either timestamped or uniformly sampled. The method comprises two distinct phases: a learning phase and a compensation phase. During the learning phase, which typically comprises 5 to 10 fringes, the algorithm first estimates the motion of the target in a manner that is unaffected by periodic errors. This information, along with the distribution of measured phase angles, enables the algorithm to infer a compensation function which effectively corrects for periodic errors. Our novel approach enables robust compensation across a broader range of interferometric sensor applications.

[1] P.L.M. Heydemann, 1981, Applied Optics **20(19)**, 3382.