

Photonic gear for ultra-sensitive tilt displacement measurements

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Abstract: We demonstrate a compact and ultra-sensitive method for measuring angular tilt by optically encoding it into the polarisation rotation of light undergoing double passage through a polarisation grating.

Precise measurement of angular tilt is critical in a wide range of applications, from advanced metrology to precision alignment and surface profile measurements. Optical techniques are particularly advantageous for angle measurements due to their non-contact nature, which is well suited for delicate or deformable components. In recent years, structured light—where properties such as amplitude, phase, or polarization are tailored in the transverse plane—has emerged as a powerful tool in optical metrology [1].

In this work, we propose a compact and ultra-sensitive method for measuring tilt displacements with structured light by harnessing the optical encoding concept of photonic gears [2]. This technique maps angular tilt into the polarisation rotation of a linearly polarized collimated laser beam on double pass through a polarisation grating or g-plate as shown in Fig. 1(a). The resulting power response after passing the beam through a polariser follows a super-resolving Malus’ law behaviour, with its linear region used for sensitivity extraction (Fig. 1(b)). We demonstrate excellent agreement of the experimentally obtained sensitivities with the theoretical predictions and are presented in Fig. 1(c). Using a low power laser source, we measured tilt displacements with a maximum sensitivity of $290 \pm 18 \mu\text{W}/\text{mrad}$. The proposed approach offers excellent stability, compactness and ease of implementation while relying on cost-effective optical elements. Our results may have a significant impact on research and industry, particularly in the development of advanced metrological systems.

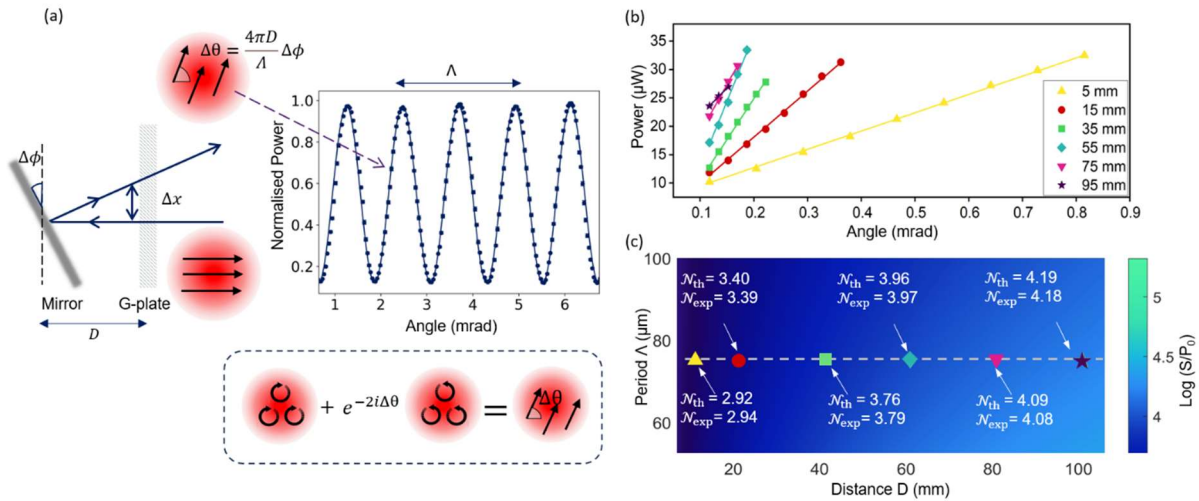


Fig. 1 (a) Illustration of the gear effect where the angular tilt is encoded into the polarisation rotation of a laser beam that maps to a corresponding point on the experimentally obtained Malus’ law curve with periodicity determined by Λ , the spatial period of the g-plate. The lower inset shows the recombination of left and right circular polarisation components upon second passage through the g-plate to produce a uniformly linearly polarized beam rotated by $\Delta\theta$. (b) The linear region of the Malus’ law curve is plotted for different mirror to g-plate distances D from which the sensitivities S are obtained. (c) The experimentally obtained results of normalised sensitivities $\mathcal{N} = \log(S/P_0)$ (mrad^{-1}), where P_0 is the laser power, are compared with the theoretical predictions for the different D .

References

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- [2] Raouf Barboza, Amin Babazadeh, Lorenzo Marrucci, Filippo Cardano, Corrado de Lisio, and Vincenzo D’Ambrosio, “Ultra-sensitive measurement of transverse displacements with linear photonic gears,” *Nat. Commun.* **13**, 1080 (2022).