传统技术与深度学习协同赋能单帧 高精度条纹图案分析

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为了实现条纹图案分析技术在速度、精度、可重复性和泛化性等方面的性能突破，继承前人在条纹分析领域多年积累的丰富经验和认知，传统单帧条纹分析方法与数据驱动的深度学习技术相辅相成、相得益彰，是大势所趋也是必经之路。

南京理工大学陈钱、左超教授团队提出了一种融合物理模型的深度学习条纹图案分析方法 (PI-FPA)，该方法结合了传统单帧条纹分析方法和深度学习技术各自的优势，实现了快速、高精度且兼具高泛化性的单帧条纹相位测量。具体地，PI-FPA 集成了一个“学习增强型”傅里叶变换条纹投影轮廓术 (LeFTP) 模块和一个轻量化网络。融合物理模型的 LeFTP 模块具有较强的泛化性，可以为网络训练阶段看不见的新型样本提供可靠的相位结果，同时潜在地规避了监督学习方法收集大量高质量数据的要求。使用轻量化网络对 LeFTP 模块输出的初始相位进行优化，以较低的计算成本提升单帧条纹相位测量的精度和计算效率。

PI-FPA 不仅像传统神经网络一样学习训练数据的内在统计特征，同时还能学习描述图像形成的物理法则，实现了高精度、高计算效率的单帧相位重构，并展现出了对复杂形貌、材质的良好泛化性能，为复杂、高速运动物体的单帧三维面型测量开辟了新途径。

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The synergy of traditional techniques and deep learning enables single-frame high-precision fringe pattern analysis

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For many optical metrology techniques such as interferometry, digital holography, and fringe projection profilometry (FPP), fringe pattern analysis is the primary focus of research for recovering the underlying phase distribution from the recorded fringe patterns. The accuracy and efficiency of phase retrieval from fringe patterns are essential to dynamically reconstruct various desired physical properties of the objects.

The research groups of Prof. Qian Chen and Chao Zuo at Nanjing University of Science and Technology established the theoretical framework for phase shifting profilometry and temporal phase unwrapping and developed a series of composite phase shifting methods for fast 3D measurement, including bi-frequency phase shifting, 2+2 phase shifting, geometric constraints based composite phase shifting, and micro Fourier transform profilometry. As a result, the FTP technique is limited to measuring smooth surfaces with limited height variations.

The proposed physics-informed deep learning technique for fringe pattern analysis (PI-FPA) not only learns the inherent statistical characteristics within the dataset like traditional neural networks, but also masters the physical laws describing image formation, realizing single-frame phase reconstruction with high precision and high computational efficiency, while exhibiting its good generalization to rare samples never seen by the network.

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