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Polarization unlocks scene-level 3D imaging

David Brady*

Abstract: Scene-level high-precision 3D imaging remians a key challenge due to the trade-offs between imaging distance and accuracy. While polarization-based 3D imaging offers potential, it offen fails facing "discontinuous" targets—environments where multiple objects are separated by space resulting from surface normal integration. A recent work integrating binocular stereo vision with polarization information successfully recovers depth by iteration. This intergation-free appoach paves the way for scene-level high-precision 3D imaging and future applications.

Keywords: scene-level 3D imaging; polarization; discontinuity; binocular stereo; integration-free

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Polarization-based 3D reconstruction is a transformative technology that enables pixel-level precision without the traditional trade-offs between imaging distance and accuracy. By capturing the specific oscillation patterns of light waves as they reflect off surfaces, this method provides critical data for autonomous driving, remote sensing, and complex scene perception[1–4]. While historically powerful, this technique has faced a significant hurdle: moving from the reconstruction of single, isolated objects to complex, large-scale natural scenes[5]. In the letter "Scene-level Passive Polarization 3D Imaging", Liu et al. demonstrate a novel approach that integrates binocular stereo vision with polarization information to achieve high-precision, scene-level imaging[6]. The primary challenge in polarization-based imaging has been reconstructing "discontinuous" targets—environments where multiple objects are separated by space. Traditional methods rely on surface normal integration, which fails when the geometry is not a single continuous surface. Liu et al. solve this problem by jointly and iteratively combining pixel-level surface normals (from polarization) and absolute scale information (from stereo vision) as mutual constraints, as illustrated in Fig. 1(a) and 1(b).

Unlike classical approaches recovering depth through normal integration[7], this method integrates stereo vision with polarization information, modeling the 3D reconstruction of discontinuous scenes into a mathematical optimization problem. Pixel-level surface normals derived from polarization and absolute scale information provided by stereo vision are combined as mutual constraints under a unified optimization framework. Iterative optimization resolves discontinuous targets and achieves accurate true depth, as illustrated in Fig. 1(c).

Large-scale scene 3D reconstruction requires dynamic reconstruction capabilities, thus unavoidably facing the problem of multi-frame image fusion. The authors design a scale normalization strategy to globally align and spatially calibrate multi-view measurement data, effectively eliminating scale drift issues. Finally, high-quality 3D reconstruction of natural scenes is accomplished through multi-frame point cloud fusion, see Fig. 1(d) to 1(g). Experiments demonstrate that this method can achieve scene-level and high-precision 3D reconstruction at video rates, offering a novel and effective solution for scene-level 3D imaging.

This research has profound significance for 3D imaging applications in autonomous driving, scene perception, and other fields. It expands reconstruction ability from a single object to complex natural multi-objects and is expected to comprehensively improve application effects. Despite its promise, practical implementation still faces challenges. For example, the currently developed system is fixed-focus. How to adapt to natural large-scale scenes of various scales and different distances is worth exploring to develop more adaptable zoom systems. In scenarios with large-moving targets such as pedestrians and cars[8], how to

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Wyant College of Optical Sciences, The University of Arizona, Tucson 210094, America.

*Correspondence: D Brady, E-mail: djbrady@arizona.edu

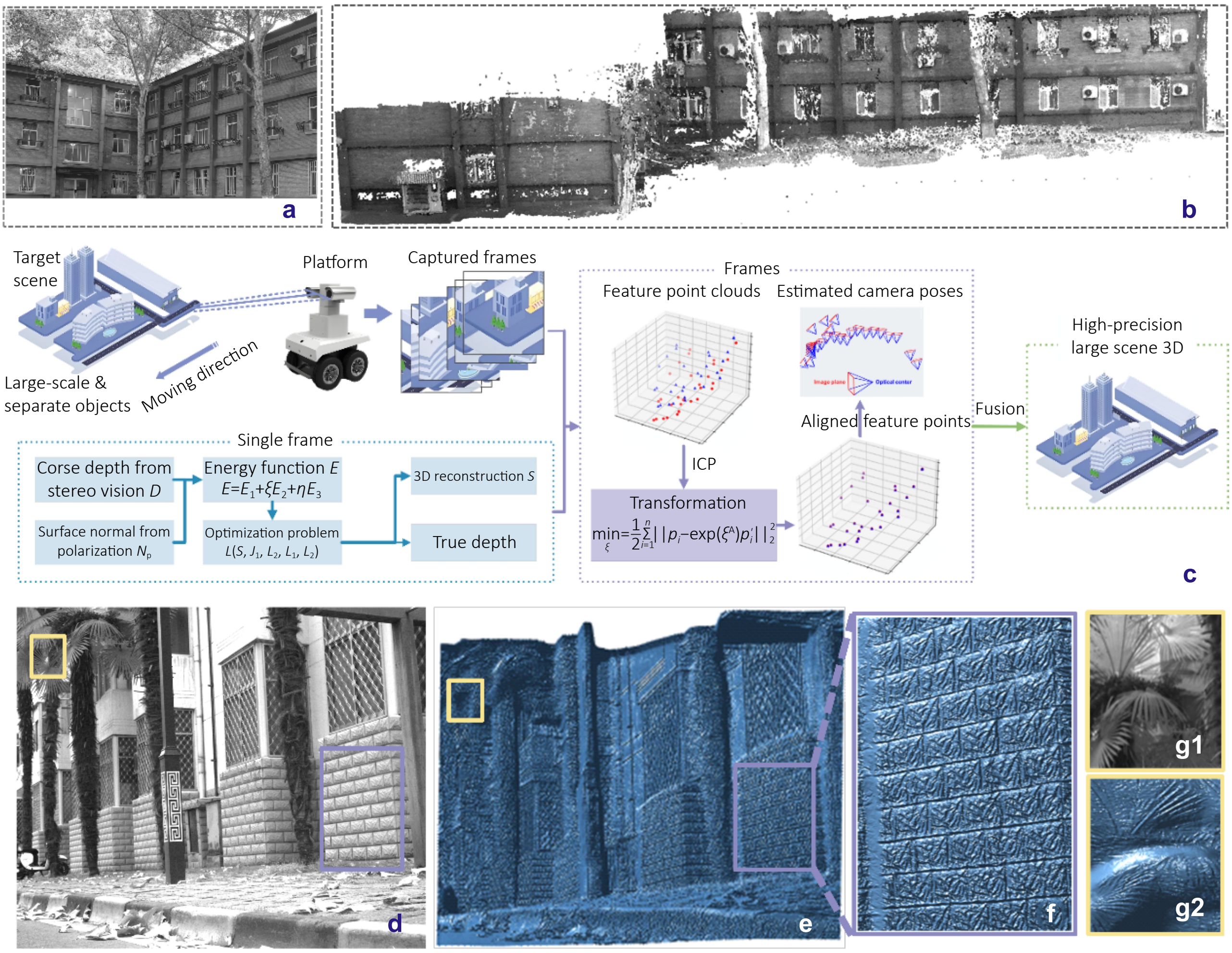

Fig. 1 | (a) Illustration of a reconstructed natural scene: directly captured image of partial scene. (b) Finally aligned and fused point clouds of the large scene. (c) Overview of the scene-level passive polarization 3D imaging method. Detail analyses of a natural scene: (d) intensity map; (e) reconstruction illustration; (f, g) details presentation. Figure reproduced from ref.[6], under a Creative Commons Attribution License.

ensure consistent fusion of feature points across multi-frame images is also crucial. Further research could focus on more adaptable parameter selection methods and more effective optimization models for complex large-scale scenes.

Finally, it is worth noting that the same team proposed a 3D imaging method based on normal self-calibration using the polarization characteristics of mixed reflected light. It can eliminate dependence on auxiliary equipment of polarization-based 3D imaging and effectively enhance its universality. Tian et al. achieved real depth information in polarization-based 3D imaging based on a linear relationship between real depth and polarization-acquired depth, although this can only be used for single continuous targets[9]. These advances highlight the critical role of solving normal correction and real depth acquirement problems in the evolution of polarization 3D imaging, as well as the difficulty of high-precision 3D imaging of natural scenes. This research marks a profound shift in imaging capability, expanding 3D reconstruction from single objects to complex, multi-object natural environments. By solving the core issues of normal correction and real depth acquisition for large-scale scenes, this work sets a new standard for the evolution of passive 3D sensing.

References

1. Wang JZ, Cossairt O, Willomitzer F. 3D imaging of complex specular surfaces by fusing polarimetric and deflectometric information. *Optica* **12**, 446–450 (2025).
2. Shen ZC, Zhao F, Ni YB et al. Extended monocular 3D imaging via the fusion of diffraction and polarization-based depth cues. *Optica* **12**, 872–878 (2025).
3. Yang K, Liu F, Liang SY et al. Data-driven polarimetric imaging: a review. *Opto-Electron Sci* **3**, 230042 (2024).
4. Han PL, Cai YD, Liu F et al. Computational polarization 3D: new solution for monocular shape recovery in natural conditions. *Opt Lasers Eng* **151**, 106925 (2022).
5. Lei CY, Qi CY, Xie JX et al. Shape from Polarization for Complex

Scenes in the Wild. In *IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)* 12622-12631 (2022).
6. Wang X, Han PL, Luo XY et al. Scene-level passive polarization 3D imaging. *Opto-Electron Adv* **9**, 250267 (2026).
7. Kadambi A, Taamazyan V, Shi BX et al. Polarized 3D: high-quality depth sensing with polarization cues. In *IEEE International Conference on Computer Vision (ICCV)* 3370–3378 (2015).
8. Chen ZY, Yang JW, Huang JH et al. OmniRe: Omni Urban Scene Reconstruction. In *The 13th International Conference on Learning Representations* (2025).
9. Tian X, Liu R, Wang ZY et al. High quality 3D reconstruction based on fusion of polarization imaging and binocular stereo vision. *Inform Fusion* **77**, 19–28 (2022).

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