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Multi-Dimensional Optical Sensing and Imaging in Degraded Environment (Keynote Address)

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Abstract: This keynote presents an overview of multidimensional imaging approaches for sensing, visualization, detection, and classification in degraded-environments. © 2025 Bahram Javidi

1. Introduction

Sensing, imaging, detection, and classification in degraded environment is pivotal for many applications of interest in different media including air, ground, and under water. Photons provide many degrees of freedom to record, reconstruct, and process the captured scene to obtain valuable information. The photon degrees of freedom include spatial, polarimetric, temporal, and multispectral bands.

While optics offers large bandwidth and high spatial resolution, optical transmission suffers in scattering media such as fog, turbid water, smoke, etc. In this keynote address, we present an overview of recently published work on a variety of multidimensional optical imaging approaches to investigate their performance in tasks such as detection, classification, ranging, and visualization in degraded environments [1-27]. Recently, progress in this domain has been made using physics informed Bayesian neural networks for image restoration in low illumination [1]. Polarimetric 3D imaging profilometry in degraded environmental conditions such as occlusion and low light and occlusion has been reported 2]. The impact of noise on the longitudinal resolution of 3D integral imaging in the presence of noise has been evaluated [3]. Passive 3D ranging and depth estimation of partially occluded objects using mutual information and Bayesian optimization have been investigated [12]. 3D object tracking with mutual information and Bayesian optimization have shown to be effective [8]. Information theoretic analysis have been shown to be effective to assess 3D imaging information loss in degraded environments [7]. 3D object detection through fog and occlusion using passive 3D imaging have been compared to active (LiDAR) sensing in a Lab setting [15]. Progress has been made in improving the computational efficiency and performance by investigating an end-to-end integrated pipeline for underwater optical signal detection using 1D integral imaging capture with a convolutional neural network [13]. In turbid under water circumstances, high-speed 3D imaging for sensing and visualization of dynamic underwater events has been reported [6].

Both lens based and lensless sensors in visible and long-wave IR domains [4] have been reported in degraded environments. Lensless systems use a thin pseudorandom phase encoding mask instead of a lens. Robustness of single random phase encoded lensless imaging systems in presence of camera noise [9], and its lateral resolution [14] have been discussed. Lensless object classification in long wave infrared using double random phase encoding has been reported [4]. High-speed temporal optical signal detection in turbid media using lensless single random phase encoding has been demonstrated [27]. This keynote-address presents an overview of multidimensional imaging approaches for sensing, visualization, detection, and classification in degraded-environments. Applications such as high-speed optical signal detection in turbidity, polarimetric 3D profilometry, low-light conditions, and obscurations are discussed.

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