

Optical Sensing, Imaging, and Detection in Turbid and Degraded Environment (Keynote Address)

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Abstract—Optical sensing, imaging, and detection in degraded and turbid environments is a challenging problem and there are many applications. Applications include oceanography, underwater communication, imaging in fog, low light, occlusion, autonomous navigation, security, defense, surveillance, etc. Conventional sensing and imaging systems are not capable of addressing these challenges and thus dedicated hardware and algorithms are needed. Sensing and imaging in degraded environments causes light scattering and absorption which adversely affect image quality and lowers signal to noise ratio, and compromising the system performance. This Keynote Address presents an overview of multi-dimensional optical sensing and imaging systems and dedicated algorithms designed for applications in degraded environments including operation in turbid water.

Keywords—*imaging in degraded environment, underwater imaging in turbidity, multidimensional sensing and imaging*

I. INTRODUCTION

Optics is attractive for sensing, imaging, communication, visualization, and classification as it offers large bandwidth and high spatial resolution. However, photons scatter during optical transmission in fog, turbid water, smoke, etc. This Keynote Address paper presents an overview of previously published papers on using multidimensional optical systems for sensing, imaging, visualization, detection, and classification in degraded environments including underwater sensing, detection, and imaging in turbidity [1-28]. We shall review a variety of optical systems and algorithms to address sensing, imaging, detection, and classification in scattering environment. Degraded environment includes fog, turbid water, and other types of obscurations. We shall investigate their performance in tasks such as signal detection, object classification, ranging, and visualization in degraded environments. Both lens based systems and lensless systems utilizing thin pseudo-random encoders will be discussed.

Integral imaging (InIm) is a passive Three-dimensional (3D) imaging technique [29, 1-10]. The capture stage records multiple perspectives of a scene. It is capable of measuring the object depth and image through partial environmental obscurants. The reconstruction can be performed optically or numerically [computationally] by reconstructing depth-sliced images. InIm can segment objects of interest from occlusions and background noise.

Recently, high-speed temporal optical signal detection in turbid media using lensless single random phase encoding has been reported [1]. Physics informed Bayesian neural networks have been reported for image restoration in low light illumination and turbidity [2, 8].

3D integral imaging polarimetric profilometry in occlusion and low light has been investigated in [3]. The longitudinal resolution of 3D integral imaging in noisy conditions has been evaluated in [4]. Mutual information and Bayesian optimization have been used as an information theoretic metric to analyze passive 3D ranging and depth estimation of partially occluded objects [10]. Furthermore, tracking of 3D objects has been performed with mutual information and Bayesian optimization [8]. 3D imaging information loss in degraded environments has been measured using Information theory [5]. Passive 3D integral imaging and active LiDAR sensing have been compared in a Lab setting for 3D object detection through fog and occlusion [12]. Various hardware architectures have been investigated for imaging in degraded environments. Recently, an end-to-end integrated pipeline for underwater optical signal detection has been reported. It is based on a 1D integral imaging capture with a convolutional neural network processing [13]. This approach improves the computational efficiency and performance. High-speed 3D imaging in turbidity for sensing and visualization of dynamic underwater events has been investigated [30]. This approach can operate at mega frames per second.

Lensless imaging that use a thin pseudo-random mask to capture the information about the object and/or scene have been investigated in degraded environment [1, 7]. Typically, deep learning algorithms are used to analyze the captured information. In [1], high-speed temporal optical signal detection in turbid media using lensless single random phase encoding is reported. In [7], underwater optical signal detection using diffuser-based lensless imaging has been reported. The experiments in this report [7] are performed in turbid water. Lensless object classification in long wave infrared domain using double random phase encoding with thin materials instead of lenses are reported in [31]. A number of papers have investigated the robustness of lensless single random phase encoding systems to noise, camera pixel size, sampling, etc. [32-34].

In summary, this keynote address paper presents an overview of our reported research in imaging in degraded environments. Both lens based systems and lensless systems are discussed. The reported approaches are robust, highly efficient, compact, and noise-resilient. Various applications including visualization, object and signal detection, and depth estimation are presented [1-35].

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What is the preferred PRESENTATION TYPE ? (Oral / Poster / Oral and Poster available)	Oral
Is the presenter a STUDENT ? (Yes / No)	No
Will the presenter apply for the STUDENT POSTER AWARD , provided he or she is a student? (Yes / No)	N/A