Correlation Plenoptic Imaging

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Traditional optical imaging faces an unavoidable trade-off between resolution and depth of field (DOF). To increase resolution, high numerical apertures (NA) are needed, but the associated large angular uncertainty results in a limited range of depths that can be put in sharp focus.

Plenoptic imaging was introduced a few years ago to remedy this trade-off. To this end, plenoptic imaging reconstructs the path of light rays from the lens to the sensor [1]. This is practically achieved by inserting a microlens array in the conjugate plane of the object (as created by the main lens), and moving the sensor in the conjugate plane of the main lens (as created by each microlens). The microlens array also enables the single-shot acquisition of multiple-perspective images, thus making plenoptic imaging one of the most promising techniques for 3D imaging. Plenoptic imaging is currently used in commercial digital cameras enhanced by refocusing capabilities. A plethora of innovative applications, from 3D-imaging, to stereoscopy, and microscopy are also being developed (e.g., [2]). However, the improvement offered by standard plenoptic imaging is practical rather than fundamental: the increased DOF leads to a proportional reduction of the resolution well above the diffraction limit imposed by the lens NA [1]. Also, the change of perspective is effectively strongly limited by the small field of view of the microlenses [1].

We demonstrate that this fundamental limitation can be overcome by taking advantage of the position-momentum correlation characterizing both entangled and chaotic sources. In Correlation Plenoptic Imaging (CPI), we exploit the spatio-temporal correlation of such light sources to push plenoptic imaging to its fundamental limits of both resolution and DOF [3-6]. The scheme for the theoretical and experimental demonstration of CPI with a chaotic source is reported in Fig. 1 [5,6]. By measuring intensity correlations between the two sensors, multiple images of the object can be retrieved on S_a, and are focused if the optical distance z_a is equal to the distance z_b. Each image corresponds to a different pixel of S_b, hence to light emitted by a different point of the source. Information encoded in the intensity correlation function can be used to effectively refocus largely out-of-focus images, while keeping diffraction-limited resolution. The intensity correlation function thus possesses plenoptic imaging properties, namely, it encodes both the spatial and the directional information enabling its key refocusing capability. As shown in the right panel of Fig. 1, CPI enables a combination of resolution and DOF that is not accessible to classical imaging systems. In particular, we have demonstrated diffraction limited imaging with a DOF increased by a factor of three with respect to standard imaging (point C in Fig. 1).

Our results represent the theoretical and experimental basis for the effective development of the promising applications of plenoptic imaging. The plenoptic application is the first situation in which the counterintuitive properties of correlated systems are effectively used to beat intrinsic limits of state-of-the-art imaging systems.

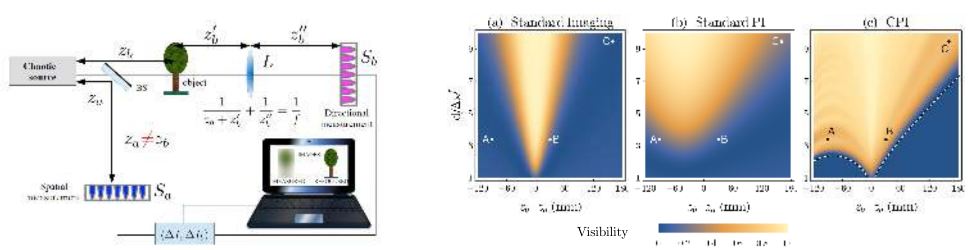

Figure 1: (left panel) CPI setup with chaotic light. (right panel) Visibility of a double-slit mask in the three indicated imaging systems. Points A, B, and C represent experimental measurements of out-of-focus and refocused images.

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