

Robustness of single random phase encoding lensless imaging systems to reducing number of sensor pixels by orders of magnitude and increasing sensor pixel size

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ABSTRACT

In this paper, we overview previously published works on the robustness of diffuser-based single random phase encoding (SRPE) lensless imaging system to sensor parameters such as pixel size and number of pixels. Lensless imaging systems are cheaper, more compact, and more portable than their lens-based counterparts due to the absence of expensive and bulky optical elements such as lenses. Our recent work has shown that the performance of an SRPE system does not suffer appreciably as we increase the pixel size of the sensor and reduce the number of pixels of the sensor. For example, we have shown that reducing the number of sensor pixels by orders of magnitude does not appreciably affect the deep neural network assisted classification accuracy of SRPE systems. Thus, providing many benefits in terms of data processing and storage. In addition, the lateral resolution of the SRPE system is robust to reducing the number of pixels of the sensor and increasing the pixel size. Our results indicate that SRPE systems may be more advantageous, compared to their lens-based counterparts, in computationally constrained environment.

Keywords: Lensless imaging, single random phase encoding, SRPE, dimensionality reduction, lateral resolution, diffuser.

1. OVERVIEW

In this paper, we overview some of the previously reported work [1,2] on the robustness of diffuser-based single random phase encoding (SRPE) lensless imaging systems [1-5] to reduction in the number of image sensor pixels and increase in the size of sensor pixels. SRPE systems, unlike conventional lens-based systems, use diffusers to map the incoming object information on image sensors. This absence of lenses, in addition to making these systems significantly less expensive, increases their field-of-view, depth-of-field and renders them considerably more compact and field-portable. Additionally, due to diffusers with high scattering angles spreading the object information evenly on an image sensor, the recorded intensity patterns contain a fair amount of redundancy. For objects with frequency bandwidth below a certain threshold, this means that the entire input information can be retrieved from a very small subset of pixel intensities [6]. This is in contrast with lens-based systems where often the full recorded intensity is required for purposes such as classification. In this overview, we highlight some recent works that leverage this property of SRPE systems to maintain high classification accuracy and excellent resolution under significant dimensionality reduction as well as increase in sensor-pixel size. Additionally, while increasing the numerical aperture of a lens-based system is expensive, doing so for diffuser-based lensless systems is considerably easier and incurs little to no extra cost.

Our system, as shown Figure 1(a), consists of a coherent StingRay laser diode of 1 milliwatt power and 639 nanometer wavelength that illuminates the sample, a glass slide upon which a sample is placed, an 80° light-shaping diffuser that spatially encodes the object field and, a Sony IMX429 CMOS sensor that records the intensity of the incoming field. The object to diffuser distance was 3.67 mm and the diffuser to image sensor distance was 26.75 mm. In the context of disease classification, optobiological signatures (OBS) obtained from this system were subjected to a local binary pattern (LBP) extraction operation and the resulting patterns were used to train an AlexNet neural network. For the purposes of resolution analysis, however, the above system was mathematically simulated and a correlation-based resolution-criterion was used to quantify and analyze the amount of change the intensity patterns undergo when two point-sources on the object plane are brought within micron distances of one another.

Our analysis [1] showed that for the identification (classification) of sickle cell disease, when the number of pixels was reduced from (1464×1936) to (100×100) , the accuracy dropped from 88.7% to ~85%, whereas the time required for training came down from 6-10 hours to 3-5 minutes. Furthermore, using only a 1D crop of the collected patterns, the

system was able to achieve $\sim 80\%$ accuracy. Figure 1(b) shows the accuracy vs pixel size trend that was observed during these experiments. More details about this analysis can be found in [1].

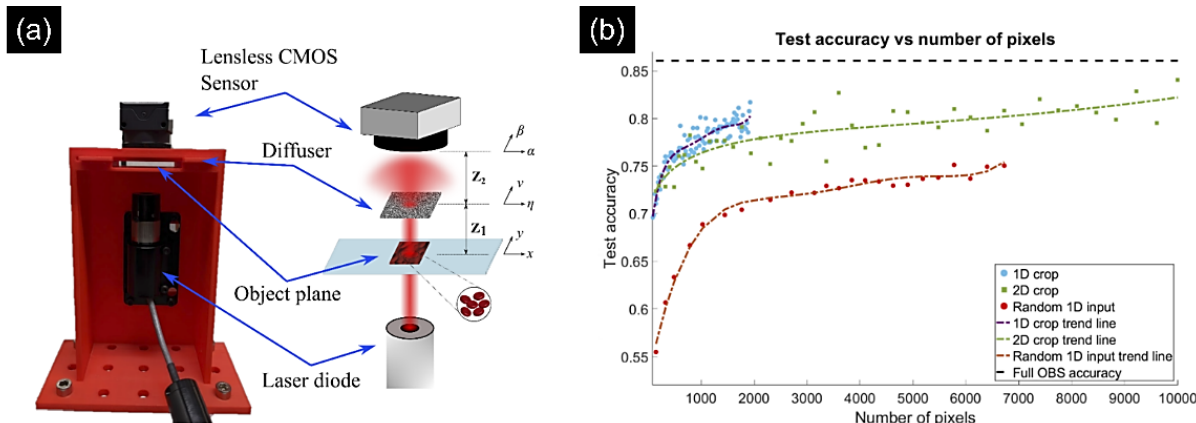


Figure 1. (a) The single random phase encoding system discussed in this work and, (b) the classification accuracy of neural networks trained with reduced number of pixels. [1]

The lateral resolution estimate of this system, as per our analysis [2], changed only by 4.27% even when the pixel size was increased by a factor of 5. When the number of pixels was reduced by a factor of 2 (along each dimension), the resolution estimate showed only a 2.73% change. Figure 2 shows the change in resolution estimate as a function of pixel size and number of pixels. An in-depth analysis of this approach can be found in [2].

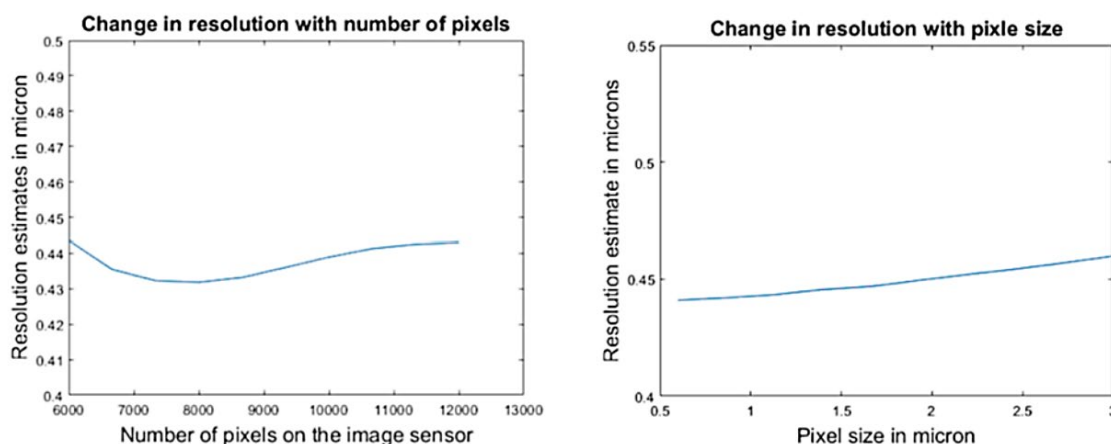


Figure 2. Change in lateral resolution estimate of an SRPE system as a function of number of pixels and pixel size. [2]

The abovementioned robustness of SRPE systems make it possible to design a high accuracy microsamples classifier with inexpensive cameras. Moreover, such classifications can be performed with only a small subset of acquired pixel intensities, reducing the amount of computational burden.

2. CONCLUSION

We have overviewed some recent developments in the robustness study of SRPE systems. Diffuser-based lensless SRPE systems, when used in the context of deep-learning-assisted classification, maintain high accuracy even when the dimensionality of the input pattern has been reduced by orders of magnitude. The lateral resolution of such systems also exhibits only a marginal change under dimensionality reduction and increase in the pixel size. These robustness properties make SRPE systems the ideal candidate for compact, inexpensive yet highly accurate classifiers.

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