# NOISE-3D: Stereoscopic imaging through scattering media

Medical tomography techniqes such as x-ray computed tomography have great advantages and still dominate medical imaging despite the fact that they suffer from drawbacks such as using ionizing radiation, and being complex in structure, and bring expensive. However, optical tomography appears to offer advantages over existing techniques. For example, it provides quantitative information on the functional properties of tissue, while being non-harmful: the radiation is non-ionizing. In recent years, researchers have invested considerable effort in developing optical tomography systems that use near-infrared light.

We recently proposed two methods for imaging objects through scattering media. In the first system, termed *noninvasive imaging by speckle ensemble* (NOISE),[1] the hidden object was reconstructed from many speckled images formed using a microlens array (MLA). Each microlens projects a small, different, speckled image of the hidden object onto a CCD camera. All noisy images from the array are shifted to a common center and then integrated into a single average picture revealing the shape of the hidden object.

In NOISE-2, a different algorithm was implemented on the same optical system, obviating the need to perform the image shift.[2] In addition to recording the speckled images of the object, we recorded images of a point-like object generated by illumination through the medium with a point source. Each sub-image of the speckled object with a corresponding sub-image of the speckled point-like object were placed together side by side in the computer. By computing the autocorrelation of each sub-image and averaging over all the autocorrelations, part of the obtained average image was a cross-correlation between the object function and a narrow point-like function. The result was a better reconstruction of the hidden object compared to the first NOISE technique.

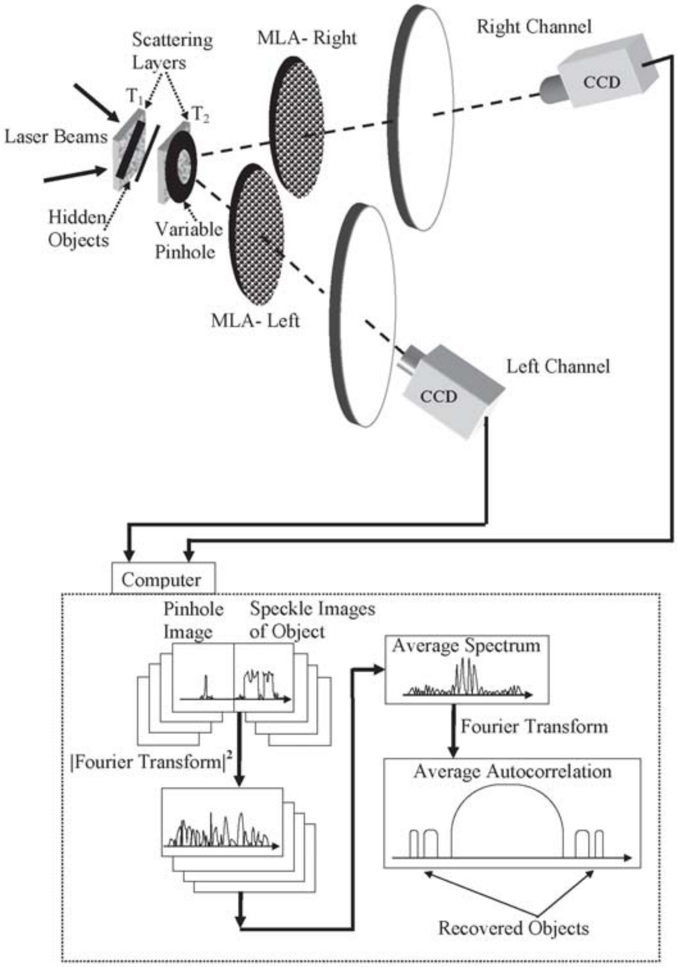

Figure 1. Schematic diagram of the proposed NOISE-3D system.

In our current work, we propose an extension of NOISE-2 to establish a new three-dimensional (3D) imaging technique of objects embedded in scattering media. In addition to object reconstruction, the object's location in 3D space is also extracted. The proposed system, termed NOISE-3D, consequently offers the advantages of revealing and acquiring depth information about objects seen through scattering media.

Figure 1 is a schematic diagram of the proposed system. The configuration consists of two MLAs accompanied by an imaging lens, a variable pinhole placed behind the second scattering layer ($T_2$), and a CCD camera. Separately, each of the left and right paths are equivalent to NOISE-2: this means that the hidden object is revealed through an average correlation with a reference point in each channel. The idea behind this point-reference technique is to ascribe the location of an object to some known location in space. The computational process performed in each channel is shown schematically in the lower part of Figure 1. Note that, in this scheme, the distance of the reconstructed object from the output plane origin is exactly the same as the gap between the object and reference point. To extract this depth information, we use stereoscopic vision.

Experiments with two separated objects of cylindrical sticks were carried out using the

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configuration shown in Figure 1. A summary of all the results is shown in Figure 2. Columns (a) and (d)—for the left and right channels respectively—show the average constructed images obtained by removing the second tissue ($T_2$). Each line in the columns shows the sticks with a different relative displacement between them, indicated in the left-most column. The effect of stereoscopic vision is clearly shown in these figures: in the right path, the relative distance between the sticks gets closer; in the left path, the distance grows as a consequence of moving the right stick longitudinally towards the MLAs.

Typical sub-images obtained from one microlens without the averaging process are shown in columns (b) and (e). The reconstructed images from the averaging process on images of the hidden sticks behind the second tissue $T_2$—with different relative displacements between the objects—are shown in columns (c) and (f). Measuring corresponding distances in different figures can succeed when there are easily-visible features on the objects as seen through both channels. In our case—using almost-vertical sticks—we choose to refer to the central point of each stick for the distance measurements. Our results indicate that the relative distances between the sticks are easily revealed with negligible error.

In conclusion, we present an optical tomography system that enables us to observe a relative depth between objects hidden in scattering media. Although we have developed the system for medical diagnostis, we believe that it can be used for several applications in the area of 3D information processing.

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**References**

1. J. Rosen and D. Abookasis, *Seeing Through Biological Tissues Using the Fly Eye Principle,* **Opt. Exp. 11,** pp. 3605-3611, 2003.
2. D. Abookasis and J. Rosen, *NOISE 2 imaging system: seeing through scattering tissue with a reference point,* **Opt. Lett. 29,** pp. 956-958, 2004.

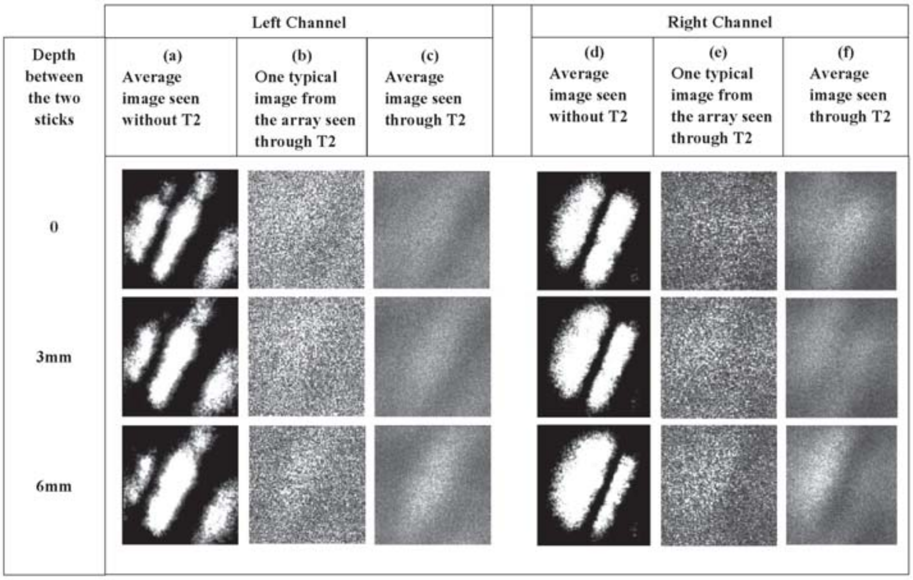

*Figure 2. Experimental results of the NOISE-3D system.*