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# Towards Reconstruction of Embedded Objects with Multiple Spackle Images for Medical Diagnostics

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**Abstract:** A new method of seeing objects hidden in scattering medium from multiple speckle images is demonstrated. The entire noisy images from lens array are digitally processed to obtain the desired image of the hidden objects.

## 1. Introduction

Over the past few years, optical imaging through turbid media has become an active research area and much efforts has been devoted to finding ways for reconstruction objects embedded in a such medium. Optical imaging has high potential application in medical diagnosis since it is safe, noninvasive and low-cost compared with the conventional radiation technique. The tendency in these imaging techniques is to work in the waveband of 700-1100nm where the absorption and the scattering of light by most soft tissue is low enough for photons to penetrate deeply into tissue and be transmitted through them. Many different reconstruction techniques have been proposed to enhance the ability of the optical imaging and each of these technologies has particular advantages and disadvantages [1]. In this work we propose a new scheme of seeing through scattering medium by emulating the fly's visual system. In that optical system several identical images from several facets are superposed together to a single common image by neural connections of the fly photoreceptors [2]. Superposing multiple images from many imaging channels enables us to see general objects hidden behind scattering layers.

## 2. System operation and reconstruction algorithm

The technique herein has been applied to several experiments that were performed using the arrangement drawn in Fig. 1 based on a simple optical imaging containing microlens array (MLA). Each lens of the array projects a different speckled image on a digital camera through imaging lens (L). In the computer the set of speckled images from the entire array are first shifted to a common center and then accumulated to a single average picture.

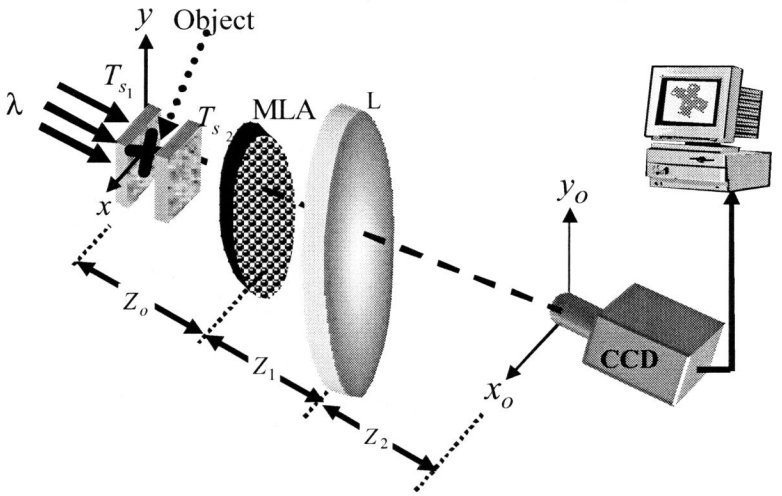



Fig. 1. Schematic diagram of experimental setup for seeing through scattering medium.

Without the scattering layers, the illuminated coherently system is characterized by a relatively narrow point spread function (PSF). This PSF is calculated conventionally as an inverse Fourier transform of the aperture of a single micro-lens. In the present case, the micro-lens imposes the system bandwidth because its numerical aperture is smaller than that of the lens L. Next, we consider the effect of the back scattering layer $TS_1$. This layer diffuses the light such that each micro-lens gets almost uniformly part of the illumination. In addition, because of the randomness of the medium $TS_1$ and its uniformity, the object is multiplied by a random phase function with almost constant magnitude. All the system is modeled as an array of several identical imaging systems, all with the same PSF. When the front scattering layer $TS_2$.is introduced into the system, the output image is distorted such that the object cannot be recognized. Since each micro-lens observes the object through a different transverse cross-section of the scattering layer, each $k$-th micro-lens together with the lens L creates a linear system characterized by a different random PSF. Our mathematical calculation [3] with the approximation of weak scattering medium and with centering each one of the sub-images to a common center and summation to a single average image, yields the object reconstruction.

### 3. Results

To verify the proposed technique, an opaque object made of chicken bones in a shape of a cross-junction with the size of $9\times9mm$ was embedded between two layers of chicken breast separated from each other by a distance of $12mm$. The thickness of the rear tissue $TS_1$ was about $3mm$, whereas the thickness of the front tissue $TS_2$, was about $8mm$. The reduced scattering coefficient of the tissues of $\mu_s$'=4.5±0.3$cm^{-1}$ was measured by the method proposed in Ref. 4. Assuming the anisotropy factor is $g$=0.965 [5], the scattering coefficient becomes $\mu_s = 128 \pm 9cm^{-1}$. The rear tissue $TS_1$ was illuminated by a collimated plane wave radiating at $632.8nm$ with $35m$W. The MLA, placed a distance of $Z_o$=$160mm$ from the object, was composed of 115×100 hexagonal refractive lenses. Only the central 132 lenses were used in the present experiments. The radius of each micro-lens is $r$=$250\mu m$ with focal length equal to $3.3mm$. Under these conditions the optical system without the tissues can resolve a minimum size of $\lambda Z_o/r \cong 0.4mm$. The resolution can be improved using lenses with larger apertures. However, this change may increase the total view angle of the system and thus the various channels may image different perspectives with different shapes of the same object. The image plane of the MLA was projected onto the CCD plane by a single spherical lens L, with a $300mm$ focal length. The distance $Z_1$ and $Z_2$ shown in Fig.1 were $520mm$ and $710mm$, respectively. In the experiment we used a CCD camera with 1280(H) ×1024(V) pixels, within $8.6\times6.9mm$ square active area. The array of all the speckled images recorded by the CCD is shown in Fig. 2. The white lines indicate the image area contributed by each single lens and were synthetically added, by the reconstruction program, on the original captured picture only for clarity. From this figure it is clear that the original object cannot be recognized from any image of the 132 different blurred images.

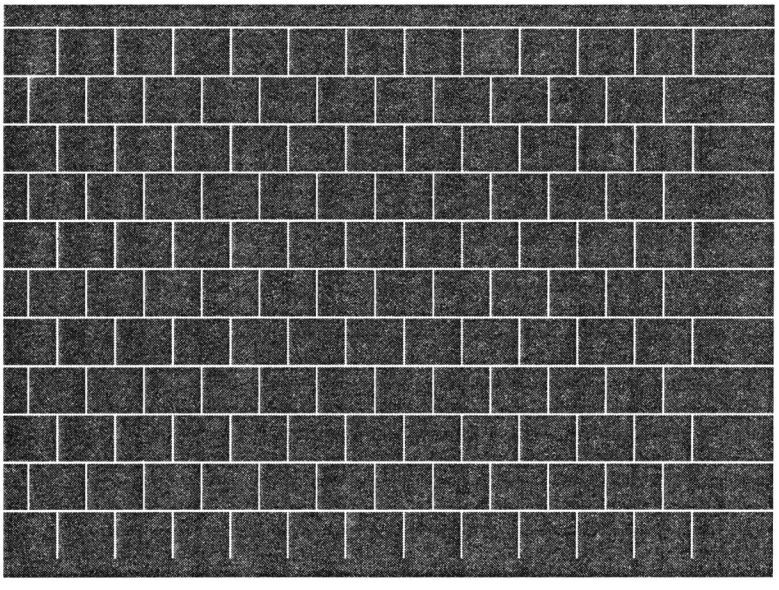
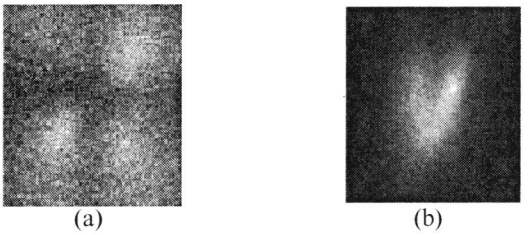


Fig. 2. 12×11 blurred images recorded by the CCD when the cross-junction sign is embedded between the two scattering layers.

Each blurred sub-image of the size 96×84 pixels from the array was extracted from the matrix, and was shifted toward a common center. We calculated the center of gravity of each contrast-inverted blurred cloud of the entire set of 132 blurred images. The center of gravity is considered as the true center of the object in each frame, and accordingly all the images are centered to have the same center of gravity. We assume that the angular difference between the most extreme view points is small enough (less than $3^{o}$ in the present experiment) to neglect the differences between all the various perspectives of the object observed from the various channels. Although the lateral shift of the object image depends on the longitudinal position of the object in the scattering layers (denoted as $Z_o$ in Fig. 1), it does not mean that one should know the longitudinal position of the object in the scattering layers in prior to image the object. The reconstruction result is shown in Fig. 3(a). In another experiments with the same setup, the object was a transparent object in the form of the letter **V** with the size of $7\times11\,mm$. The reconstruction procedure was repeated again and the results shown in Fig. 3(b).



(a) (b)

Fig. 3. (a) The reconstructed image from the array shown in Fig. 2 in the case of the cross-junction object and (b) in the case of the V shape object.

This results show the possibility of using our configuration to detect tumors, hernia or internal teeth rot for medical diagnostic in a simple and robust way at a clinical room or in the battle field.

In order to verify the need of using coherent light, we did an experiment of imaging through the same scattering layer with incoherent light under white light illumination of a Halogen lamp. Experiments show evidently that the object cannot be recognized. Incoherent light means that the object is illuminated by a bunch of plane waves with many different angles. The effect on the output image in each channel is an accumulation of many blurred images of the object shifted randomly from the true object center. Therefore, the result in each imaging channel will be smoothly blurred unrecognizable image of the object. Accumulating these images along the all channels won't enable to see through the scattering medium. In another experiment we removed the MLA and imaged the object onto the CCD with 48 times better resolution than in the setup with the MLA. Then, every successive rectangle of 48×48 pixels on the image matrix was averaged. The aim of this experiment is to check if lateral averaging over high resolved image is equivalent to averaging over many low resolved images as done in the experiment with the MLA. These results have not produced any recognizable image of the object. This shows that the procedure of averaging the low resolved MLA images is significantly superior over the averaging a single high resolved image

## 4. References

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