Stereoscopic Imaging through Turbid Media using Couple of Microlens Array

David Abookasis and Joseph Rosen

Ben-Gurion University of the Negev
Department of Electrical and Computer Engineering
P. O. Box 653, Beer-Sheva 84105, Israel

Abstract: A new method for 3D imaging of hidden objects in a turbid media is experimentally tested. Objects hidden between two biological tissues at different depths are recovered, and their 3D locations are computed.

1. Introduction

Medical tomography techniques such as X-ray Computed Tomography (CT) [1] offer great advantages and are still widely used despite the fact that they suffer from several drawbacks such as ionizing radiation, a complex structure and high-cost. The advantage of optical tomography over other medical tomography techniques is that they provide quantitative information on functional properties of tissues, while being non-harmful (the radiation is non-ionizing). Accordingly, in the recent years researchers have invested considerable effort towards developing optical tomography systems that use near-infrared (NIR) light. In the present study we suggest a simple optical tomography technique that is based on speckled images. Analogous to the fly's two eyes, two microlens arrays (MLA) are used to observe the hidden objects from different perspectives. At the output of each lens array we construct the objects from several sets of many speckled images by a technique previously suggested which uses a reference point [2]. The differences of the reconstructed images on both arrays in respect to the reference point yield the information regarding the relative depth between the various objects.

2. Fundamental concept

Figure 1 is a schematic diagram of the proposed 3D imaging system. The configuration consists of two MLAs accompanied by imaging lenses, a pinhole (implemented by an adjustable iris) placed behind the second scattering layer T_2 and conventional CCD cameras. Each path, left and right separately, is equivalent to that given in Ref [2]. In the present setup the point-source is placed in front of the scattering medium, and thus serves as a reference point instead of as a point-source of illumination. The idea behind this point technique is to ascribe the location of an object to a location of some known point in space. The computational process at each channel is as described extensively in Ref [2]. Briefly, in addition to the speckled images of the object, we recorded speckled images of a pointlike object. After collecting all the object's speckled images by using the MLA, we used the point source to illuminate the setup, and speckled patterns of this point source, through the same number of channels, were captured by a CCD. Each subimage of the speckled object is placed side by side in the computer with a corresponding subimage of the speckled pointlike source, and the two images are jointly Fourier transformed. The squared magnitudes of the jointly transformed pictures are accumulated to compose a single average joint power spectrum. Object reconstruction is achieved by another Fourier transform (FT) of this average spectrum. This process yields three spatially-separated terms at the output of each path. One term is the zero-order at the vicinity of the output plane origin. This term is equal to the sum of the pinhole autocorrelation and the object autocorrelation. The other two terms correspond to the cross-correlation between the object and the pinhole and thus, assuming the average pinhole image is close to a point, these terms approximately yield the object reconstruction. The image of the hidden object can therefore be retrieved by reading it from one of these orders. Note that in this scheme the distance of the reconstructed object from the output plane origin is related directly to the transverse gap between the object and the reference point. To extract the depth information about the object we use the principle of stereoscopic vision [3]. That is, different perspectives of our viewing system (disparity) lead to slight relative displacements of the object (depth) in the two views channels of scene.

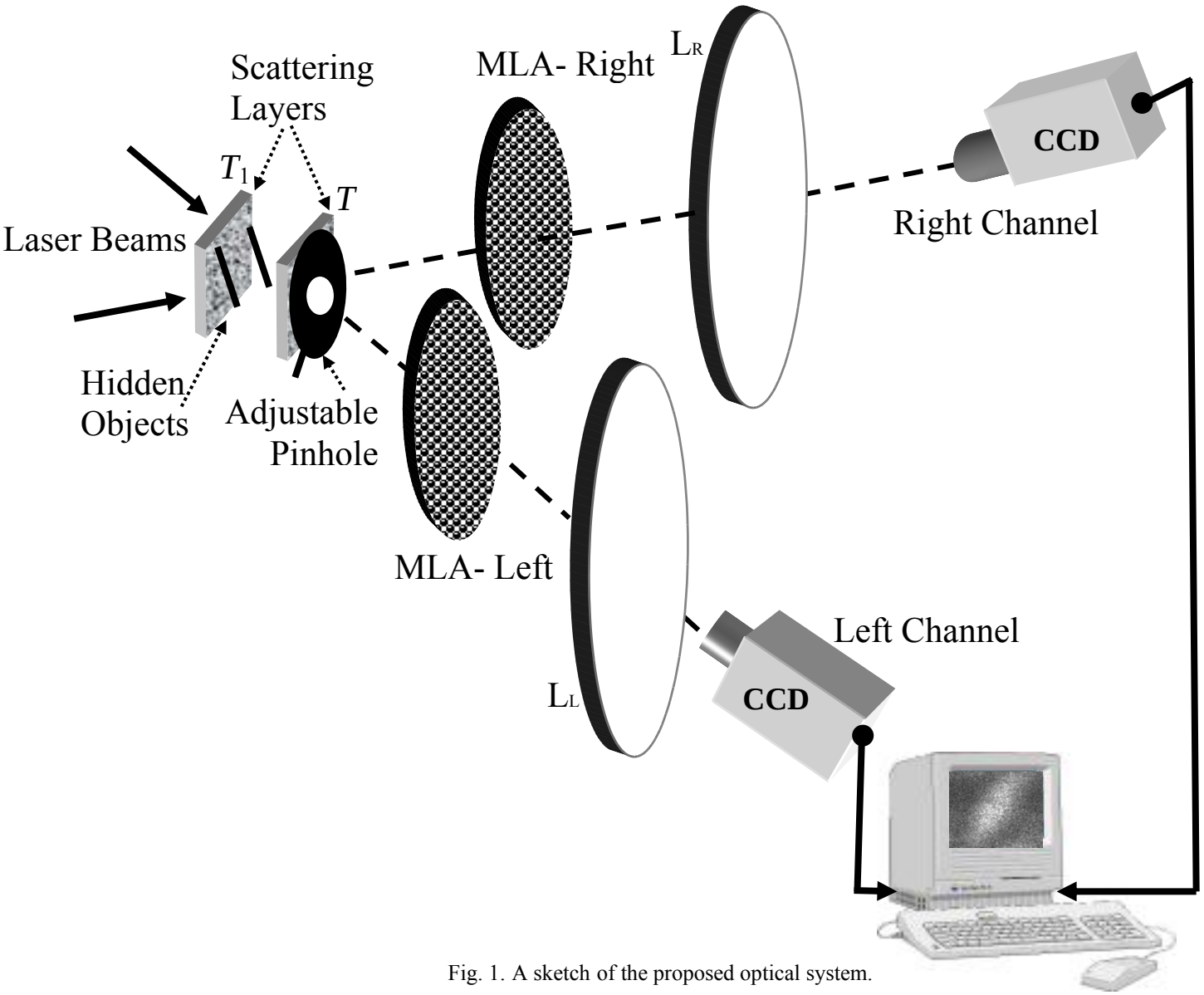


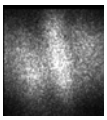
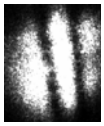
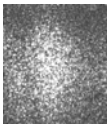
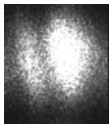
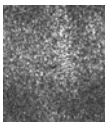
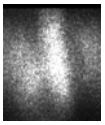
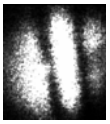
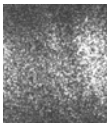
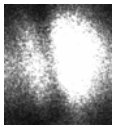
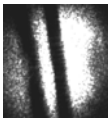
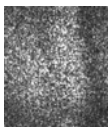
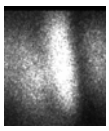
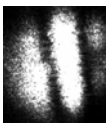
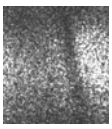
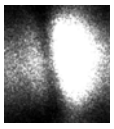
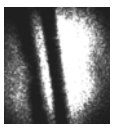
Fig. 1. A sketch of the proposed optical system.

3. Experimental Results

Experiments with two separated cylindrical sticks as observed objects were carried out using the configuration shown in Fig. 1. The sticks had a length of 20mm and a diameter of 2.1mm each. During the experiments, the left-stick was constantly attached to tissue T_1 while the right stick was moved longitudinally toward the MLAs, at three different positions. Thus, the relative longitudinal displacements between the sticks were: 0mm (the objects are at the same plane), 2mm and 4mm. The sticks were embedded between two slabs of chicken breast separated by a distance of 12mm. This scattering medium is characterized by a scattering coefficient of μ_s=128±9(cm^{-1}) [4] and absorption coefficient of μ_a≈0.2(cm^{-1}) [5]. The thicknesses of the rear tissues T_1 and the front tissue T_2, were about 3mm and 4.5mm, respectively. The reference point was created by placing a pinhole with an adjustable aperture at a short distance (22mm) behind tissue T_2, between T_2 and the MLAs. The rear tissue T_1 was illuminated by two diagonal collimated plane waves emerging from of He-Ne laser at 632.8nm with 35mw. The two MLAs were placed at a distance of 162mm from the pinhole. Each MLA consists of 42×42 micro-lenses, but only 3×8 were used in this experiment. Using more than 3 columns per channel introduces a considerable different perspective of the object into the averaged image, and thus the reconstructed image is degraded. The diameter of each micro-lens is 0.6mm and its focal length 6.3mm. The image plane of each MLA is projected onto the CCD plane by a single spherical lens L_L and L_R respectively, each with a focal length of 120mm and a diameter of 150mm. These lenses, with magnification of 1.3, matches the MLA size with the CCD size and are sufficiently large to cover the MLAs. At each channel the distance from the MLA to the imaging lens is

210mm and the distance from the MLA to the CCD plane is 280mm. The distance between the MLAs centers is 80mm. After acquiring the sets of the observed image in each path, a computer program was employed to reconstruct the sticks and to determine their distance from the MLAs adopting the stereoscopic vision formula [3]. A summary of all the results is presented in Table. 1. Columns (a) and (d) show typical sub-images obtained from a typical microlens without using the averaging process. The reconstructed images derived from the averaging process on the images of the hidden sticks with different relative displacements between the objects are shown in column (b) for the left channel, and (e) for the right channel. Note that the reconstruction of one of the sticks (the right-one from Fig. 1) in the pictures is improved as a consequence of its closeness to the scattering layer T_2, while the other stick (the left-one from Fig. 1) remains far from T_2. Columns (c) and (f) show the same reconstructed images obtained by removing the second tissue T_2 on the same setup. The effect of stereoscopic vision is clearly demonstrated in these figures by observing that in the right path the relative distance between the sticks gets smaller while in the left path the distance grows as a consequence of moving the right stick longitudinally towards the MLAs. Measuring corresponding distances in different figures can succeed only when there are well-seen indicators on the objects that are viewed from the two channels. In our almost vertical sticks we choose to refer to the central point of each stick as the object point for the distance measurements. Using these measurements our results indicate that the relative distances between the sticks without taking T_2 into account, measured on Figs. 3(c) and 3(f), are 0.302mm, 2.414mm and 4.397mm instead real distances of 0mm, 2mm and 4mm. When taking T_2 into account the relative distances between the sticks, measured on Figs. 3(b) and 3(e), are 0.24mm, 2.358 mm and 4.548mm, indicates the success of the proposed method.

Table 1. Summary of the imaging results obtained by the proposed system.

	LEFT			**RIGHT**		
Object gaps	**One image from the array (a)**	**Averaging with T_2 (b)**	**Averaging without T_2 (c)**	**One image from the array (d)**	**Averaging with T_2 (e)**	**Averaging without T_2 (f)**
d=0*mm*						
d=2*mm*						
d=4*mm*						

4. References

[1] J. G. Webster, *Minimally Invasive Medical Technology*, (IoP, Bristol and Philadelphia, 2001), Chap. 4, pp. 46-58.
[2] D. Abookasis and J. Rosen, "NOISE 2 imaging system: seeing through scattering tissue with a reference point," Opt. Lett, **29**, 956-958 (2004).
[3] Y. Shirai, *Three-Dimensional Computer Vision*, (Springer-Verlag, Berlin Heidelberg, 1987), Chap. 7, PP. 122-125.
[4] J. Rosen and D. Abookasis, "Noninvasive optical imaging by speckle ensemble," Opt. Lett, **29**, 253-255 (2004).
[5] G. Marquez, L. V. Wang, S-P Lin, J. A. Schwartz, and S. L. Thomsen, "Anisotropy in the absorption and scattering spectra of chicken breast tissue," Appl. Opt, **37**, 798-804 (1998).

AKNOWLEDGMENT: This research was supported by Israel Science Foundation grant 119/03.