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Image Reconstructions of a Portable Optical CT-Scan Using a NIR Light Source

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Abstract: 2D Image reconstructions of some phantoms have been obtained from a portable design of a transversal optical computed tomography (OCT) scan. A laser diode of an NIR (Near-Infrared) peak spectrum at 904 nm has been used as a light source through a standard technique of scanning. The phantoms used for the experiments were of cylinders of gypsum and stainless steel materials. This technique is considerably encouraging for further applications that could introduce some advantages of simply operation and low cost. *Copyright © 2010 IFSA.*

Keywords: optical tomography, phantom, NIR, gypsum, stainless steel

1. Introduction

Optical computed tomography (OCT) scan technology has been used widely in various applications of medical diagnostics, environment, chemical [1-3] as this technique uses light sources that introduces non-invasive detections. Use of optical techniques are expected able to overcome some disadvantages experienced by a common technique based on X-Ray sources such of destructive, impractical and expensive [4, 5]. The efforts to improve OCT scan techniques will be a challenging that able to offer low cost and simply operation of apparatus. Use of optical light source is considered to have more safety as no side-effect introduced because of low energies of radiation used. The use of diode laser and light emitting diode (LED) are also interesting for a design of optical tomography [6, 7]. It is a general knowledge that most of OCT scan equipments have been built-up bases on a sagittal scan

technique by referring to the attenuation of the phantom from the light source. This technique is relatively simple and low cost compare than that of the available technique based on optical diffuse tomography that is more complex in mathematical calculations and optical components used [1]. For this kind of technique, Scheel *et al*. [8] have carried out the work by using a wavelength at 675 nm of laser diode for a medical application. The concept of their works was based on the sagittal scan that will produce 2D scan contours. Hielscher *et al.* [4] and Netz *et al.* [9] have reported their experimental works on the fingers joint for sagittal scans using a laser diode in the red wavelength spectrum (650 nm).

The OCT based on a transversal cross-section scan is found to have a limited number of publications compare than that of the other techniques such of diffusion and coherence. Nevertheless, this technique could introduce more interesting in image reconstructions of phantom with simpler algorithm. Using this technique, a top view of image reconstruction obtained could inform more complete figure in 2D which allows us able to analyze further detail of the physical phenomena. Watanabe *et al.* [10] have reported their work on the phantom of lipid immersed in the water medium to obtain the image reconstruction. They obtained the image with the correction factor introduced by running the measurement using an acrylic material.

In this paper we report the preliminary result of a self-design apparatus performance of OCT scan based on a transversal imaging using an NIR (Near-Infrared) laser diode of 904 nm as a light source. The apparatus design was built-up based on the light attenuation received by a photodetector when this light beam strike the phantom to provide a 2D image reconstruction of cross-sectional area of phantom. The correction factor was introduced by running the measurement for a phantom-free in air medium. This technique is interesting as most of the image reconstruction done through the sagittal scan.

2. Theory and Experiment

A basic concept of OCT scan refers to the measurement set-up as illustrated in Fig. 1. From that figure, data collected from the detector for different scanning positions of phantom (set of data) are the attenuation of light intensities (one dimensional projection profile) after passed through the phantom. The attenuation intensities include the absorption and any scattering phenomena in the sample [10]. The absorption intensities are considered to introduce the dominant phenomenon of light received by the detector as the active area of this component is relatively small (about 5 mm diameter) which is considered able to minimize any scattering effect may occur. For those phenomena, we assume that light beam intensities will be attenuated by a phantom follows Beer Lambert's law. Therefore the projection data at a certain angle, $P_\theta(r)$ can be expressed as

$$P_\theta(r) = \ln\left(\frac{I_0}{I_t}\right) = \int_{line\ (\theta,r)} \mu(x,y)\,ds \ , \tag{1}$$

where I_0 and I_t are intensities of incident and attenuation light, respectively. $\mu(x,y)$ is the total attenuation coefficient, and ds is the differential path length along the parallel light beam. In the translational scan, changes in the position of the incident light beam introduce a change in $\mu(x,y)$. In the rotational scan, changes in the angle θ introduce a change in the position of the sample being illuminated. The above movements could be expressed into the equations for each ray (parallel light beam) as

$$r = x\cos\theta + y\sin\theta \tag{2}$$

By using the delta function, equation (1) can be rewritten as

$$P_\theta(r) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mu(x,y)\delta(x\cos\theta + y\sin\theta - r)dxdy \,, \tag{3}$$

where $P_\theta(r)$ is known as a Radon transform of a function $\mu(x,y)$. This transform will map the data from (x,y) to (r,θ). In the term of tomography, plotting the Radon transform or scanning data refers to a *sinogram* characteristic due to its sinusoid shape. Therefore, a cross-sectional image of phantom can be reconstructed using an inverse Radon transform. Detail principles of the computed tomography could be found in Thavavel *et al* [11]. For the image reconstruction and back projection methods, the Filtered Back Projection (FBP) algorithm has been used [12]. This algorithm generates the reconstruction of a single projection. A summation of the reconstruction for each single projection forms a complete reconstruction of an image's cross-sectional. In practice, only a finite number of samples will be taken from a projection, so a discrete approximation in practice could be expressed as

$$\mu(x,y) = \frac{\pi}{K}\sum_{i=1}^{K} (x\cos\theta_i + y\sin\theta_i) \tag{4}$$

From (4) there are *K* numbers of projection $P_\theta(r)$, meanwhile $\frac{\pi}{K}$ is an angle between two projections and *i* is the data point [7].

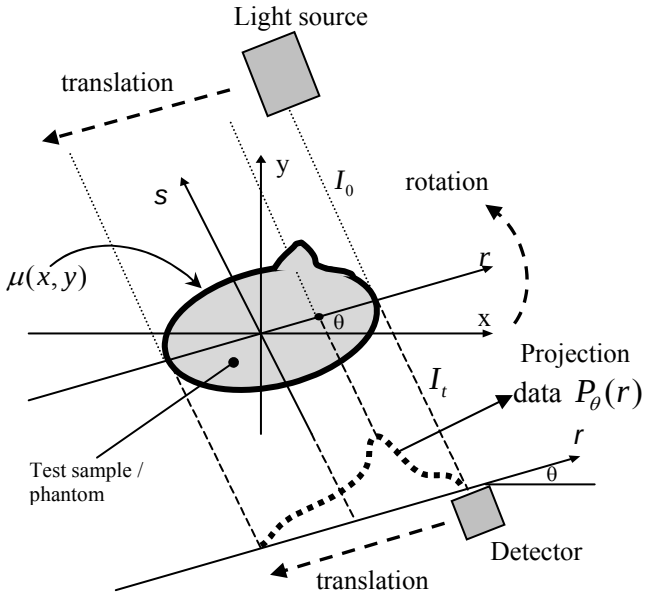


Fig. 1. Illustration of the projection data acquisition.

The OCT scan apparatus used in the measurement consists of a pair of laser diode and photodiode positioned across the phantom. This set-up allows the translation and rotational movements for a transversal cross-section process of a phantom. The distance between the laser diode and the photodetector was fixed for about 7 cm. The schematized diagram of the apparatus set-up is given in Fig. 2. The phantoms used for the measurement were of cylinders of gypsum and stainless steel materials with variation of diameters. During measurement, the phantom was fixed on the stage

meanwhile the motion part consists of laser diode and photodetector did not make any mechanical contact with the phantom. This apparatus set-up introduces a relatively low vibration during measurement. The measurements were done at room temperature at low light intensities of environment.

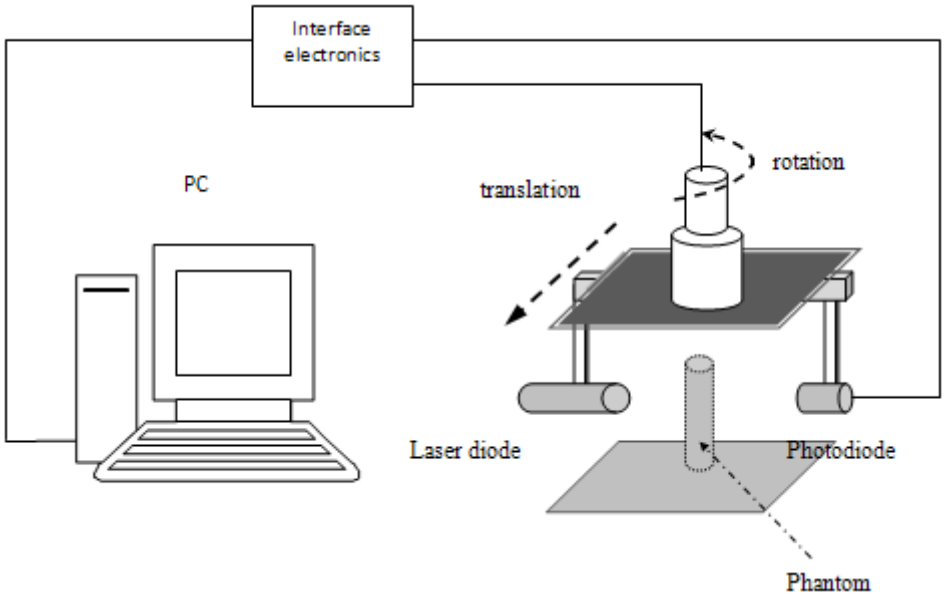


Fig. 2. Schematized diagram of the transversal optical tomography set-up used.

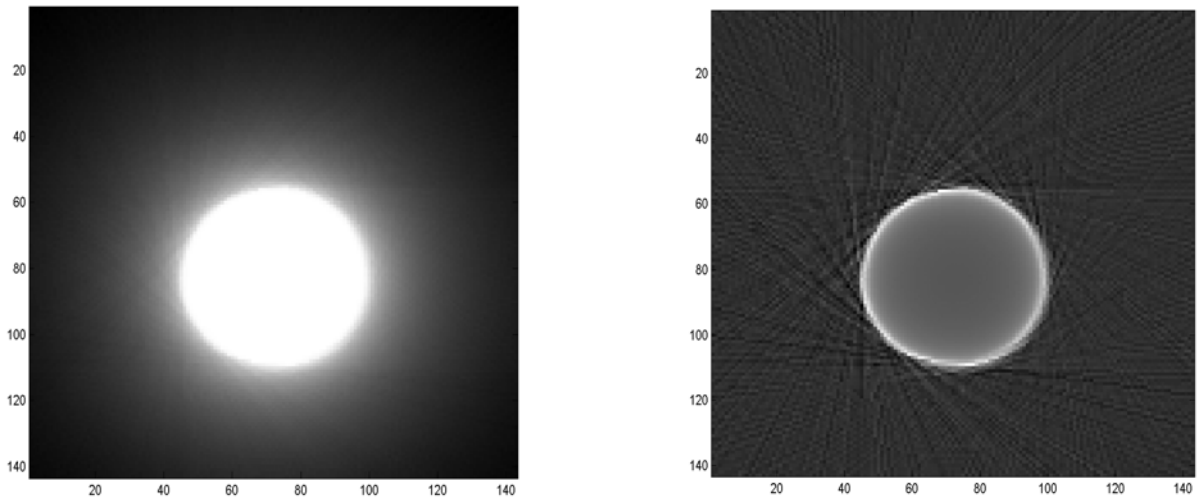
During the experiment, the translation and rotation introduce movement steps for 0.22 mm and 1.8°, respectively through the stepper motor. This movement allows the apparatus to collect the data for 200 projections for a complete scan. Scanning process including data collection of the image reconstruction of the phantom were controlled using a computer through a Delphi software. The measurement results obtained from the data collection were then processed by referring to the concept of computed tomography (CT) by means of the transmission light intensities from the source. With this strategy, the back projection could be done to obtain image reconstructions. By referring to the above points, this technique is suitable for transparent or semi-transparent media. The apparatus is able to perform a self-construction for an image reconstruction of various shapes of phantom based on a back projection method through a data extraction obtained from the measurement. Another side, use of commercialized laser diode at low power (less than 2 mW) is considered able to introduce low power consumption for the apparatus.

3. Results and Discussion

From the measurement done using a single phantom of a cylinder shape (gypsum material), the data projection has been successfully collected and then subsequently projected into 2D image reconstructions by means of a transversal (cross-section image) through a back projection method. The results obtained are given in Fig. 3, where the abscissa and ordinates are pixel (arbitrary unit). As we can see from the figure, the image of phantom observed is very bright compare than that of the other contrast levels associate with the background (Fig. 3a). The edge of phantom image shape is not clearly seen. Nevertheless, this distinguishable image shows that the apparatus is working properly to satisfy the optical CT scan technique. After a filtering process, a very bright image could be reduced its gray level to provide more clear image (Fig. 3b). From that figure, the edge of phantom image

could be found to have more clear that is surrounded by a thin ring. This ring is assumed due to the mismatch of refractive index between ambient and phantom media.

The distinguishable images after filtering process obtained have been projected into grey level for a distance along the image profile as given in Fig. 4. From the figure, the image profile after filtering process shows more sensitive variation in gray level respect to the distance. The profiling process was done immediately after the image reconstructed from the scanning process. This mechanism introduces the image reconstruction in relatively quick process. The point of a distinguishable image is very important for the determination the phantom from its background.



(a) (b)

Fig. 3. The 2D image reconstructions of the gypsum cylinder (phantom) at (a) before, and (b) after filtering process.

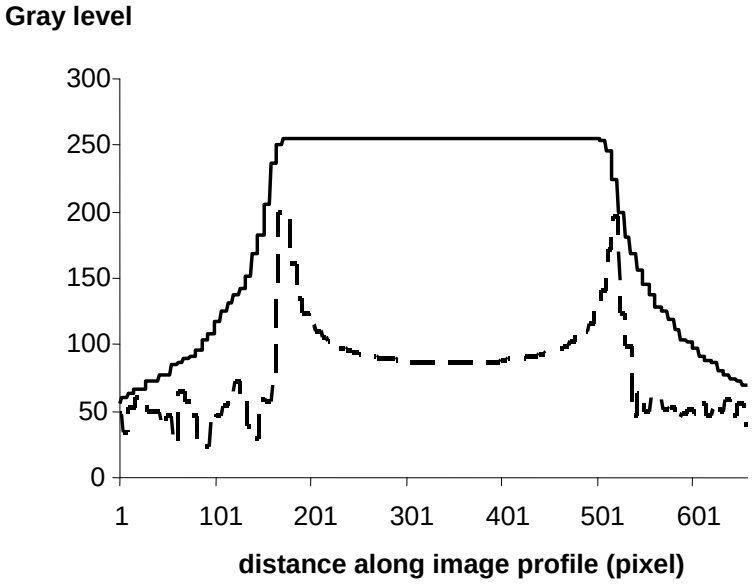


Fig. 4. The image profiles obtained (from Fig. 3) at before (solid line) and after (dashed line) filtering.

Further experiments were carried out using stainless steel cylinders with a variation of diameters for 0.5, 1.0, 1.5, and 2.0 cm. The results obtained are given in Fig. 5 (a-d). The image shapes of phantoms are clearly distinguishable from their backgrounds. The background image observed for a diameter of 1.5 cm looks a bit unsmooth compare than that of the other phantom diameters. This unsmooth image may be due to the quality of cylinder surface being scanned which is not as smooth as the others. Those four images are projected into the image profiles as shown in Fig. 6. From those profiles, the ratios of diameter of image (Fig. 6 b, c and d) respect to Fig. 6a have been calculated and found to be consistent for about 1.7. This result shows that the image reconstruction is reproducible for variation of phantom sizes used.

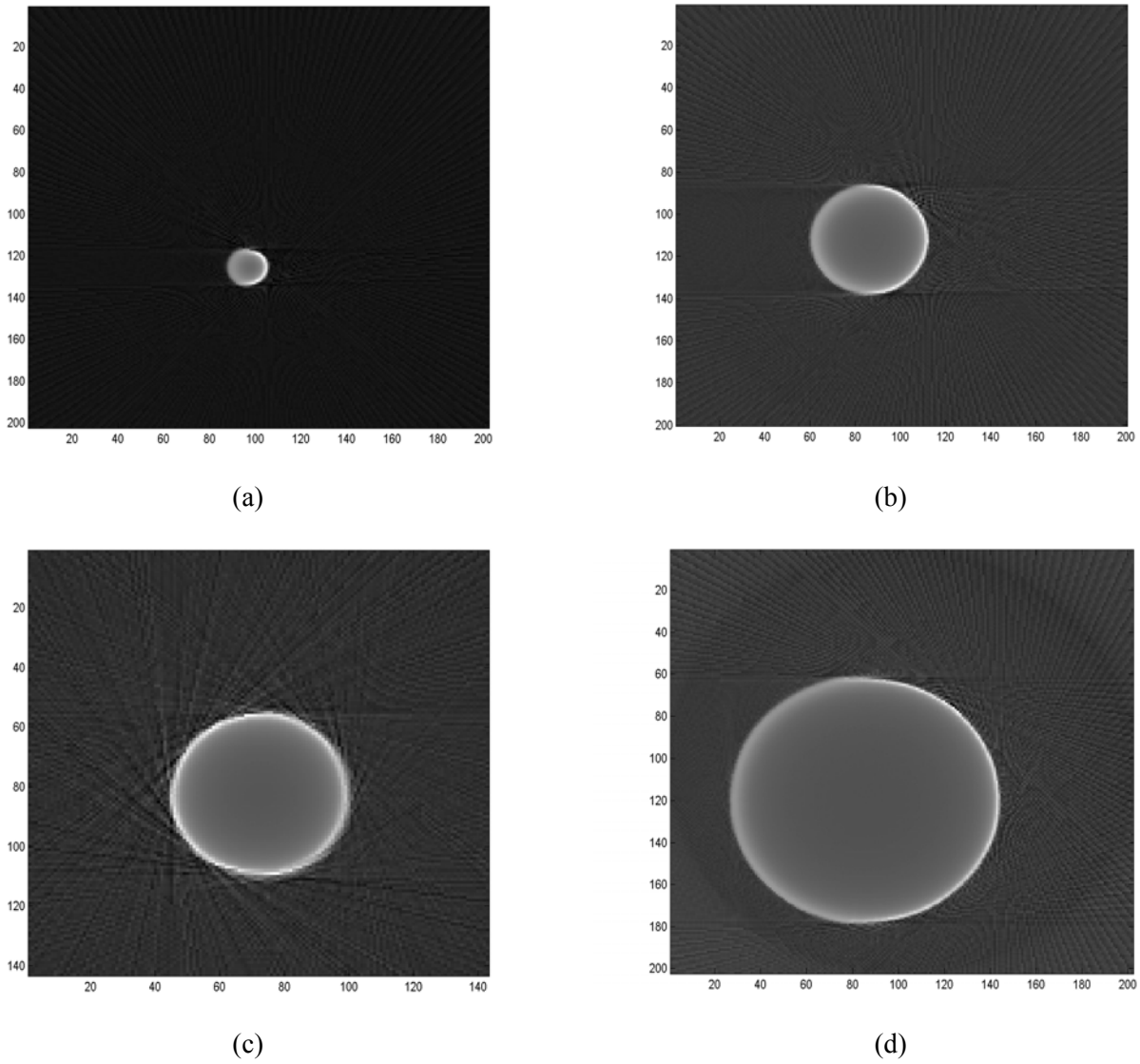


Fig. 5. 2D Image reconstructions of the phantoms of stainless steel cylinder after filtering process for a variation of diameters of (a) 0.5, (b) 1.0, (c) 1.5 and (d) 2.0 cm.

4. Conclusions

The simple operation and portable design of optical tomography has been demonstrated its capability to reconstruct 2D image for variation of phantoms (gypsum and stainless steel materials). The reconstruction was done for a transversal cross-section scan. The image profile obtained indicates the distinguishable profiles of phantom from their background.

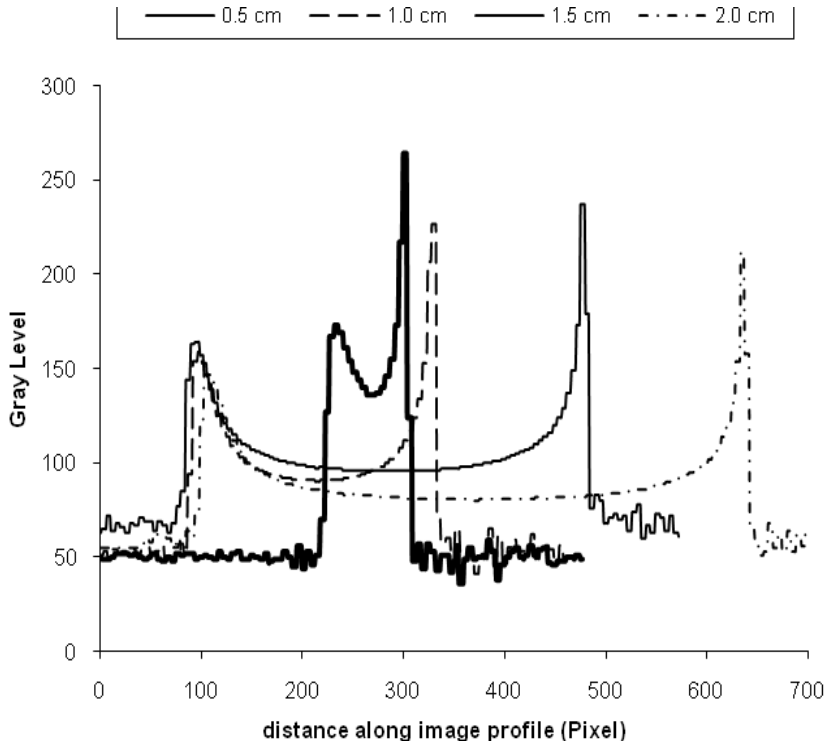


Fig. 6. The image profiles obtained (from Fig. 5.) for a variation of diameters.

These results show that the set-up apparatus with a simply algorithm have been successfully used for image reconstructions by means of the CT-Scan concept. The apparatus is considerably simple and low cost that is suitable for various applications.

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