Test target for characterizing 3D resolution of optical coherence tomography

Zhixiong Hu*, Bingtao Hao, Wenli Liu*, Baoyu Hong, Jiao Li
Division of Medical and Biological Measurements, National Institute of Metrology, No.18 Bei San Huan Dong Lu, Beijing, P. R. China, 100029
Email: huzhixiong@nim.ac.cn; liuwl@nim.ac.cn.

ABSTRACT

Optical coherence tomography (OCT) is a non-invasive 3D imaging technology which has been applied or investigated in many diagnostic fields including ophthalmology, dermatology, dentistry, cardiovasology, endoscopy, brain imaging and so on. Optical resolution is an important characteristic that can describe the quality and utility of an image acquiring system. We employ 3D printing technology to design and fabricate a test target for characterizing 3D resolution of optical coherence tomography. The test target which mimics USAF 1951 test chart was produced with photopolymer. By measuring the 3D test target, axial resolution as well as lateral resolution of a spectral domain OCT system was evaluated. For comparison, conventional microscope and surface profiler were employed to characterize the 3D test targets. The results demonstrate that the 3D resolution test targets have the potential of qualitatively and quantitatively validating the performance of OCT systems.

Keywords: optical coherence tomography, test target, 3D resolution

1. INTRODUCTION

Optical Coherence Tomography (OCT), rapidly developed in recent years, is a type of non-invasive three-dimensional imaging technology by detecting the backscattering of the samples[1]. It has been applied or investigated in many diagnostic fields including ophthalmology, dermatology, dentistry, cardiovasology, endoscopy, brain imaging and so on[2]. Optical imaging resolution is an important parameter in evaluation of the quality and utility of an OCT image acquiring system. Unlike other traditional optical imaging systems, the lateral and axial resolution in OCT is governed by independent physical principles. The Lateral resolution of OCT is similar to optical microscope, which is based primarily on the OCT beam focusing optics, while axial resolution is dictated by the coherence length of the light source.

Generally, resolution test targets including a series of two-dimensional patterns are used to measure the accuracy or performance of conventional optical imaging systems such as microscopy. However, the imaging capabilities of OCT are not only determined by conventional 2D resolution (i.e. lateral resolution) but also greatly influenced by its axial resolution. Since OCT is frequently highlighted for providing cross section images, how to evaluate its 3D resolution needs to be investigated. Generally, OCT axial resolution was characterized by putting a mirror in front of the sample arm, and then makes a FFT with the interference signal while lateral resolution was defined with traditional test targets (e.g. USAF1951 test target). Furthermore, research on point spread function (PSF) phantoms with standard-size scattering particles which utilized to analyze resolution performance of OCT instrument can be found in the literature[3-6].However, the above methods are either too time-consuming or complex to be implemented from the

International Symposium on Optoelectronic Technology and Application 2014: Laser and Optical Measurement Technology; and Fiber Optic Sensors, edited by J. Czarske, S. Zhang, D. Sampson, W. Wang, Y. Liao, Proc. of SPIE Vol. 9297, 92971S · © 2014 SPIE · CCC code: 0277-786X/14/$18 · doi: 10.1117/12.2073062

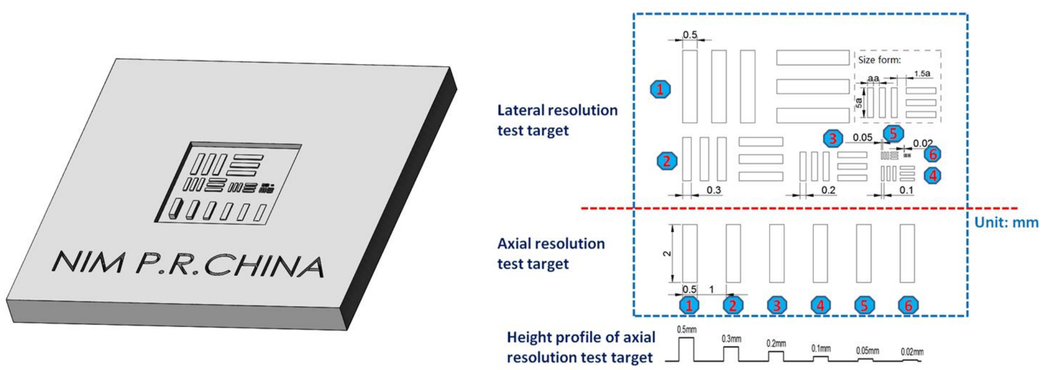
regulatory perspective. In order to tackle this challenge, many research groups have tried lithographic casting method or assembling approaches to fabricate multilayered or three-dimensional structured tissue-mimicking phantoms which can be utilized to estimate lateral and axial resolution of OCT systems[7-11].

In our research, we employ 3D printing technology to design and fabricate a test target for characterizing 3D resolution of optical coherence tomography. The test target which mimics USAF 1951 test chart was produced with photopolymer. Differing from traditional 2D USAF 1951 test chart, a group of patterns which have different thickness in depth were fabricated additionally. Therefore, the test target can provide bars with different width and thickness to discern the limitation of resolving power in three dimensions.

2. 3D TEST TARGET PREPARATION

2.1 Design

The 3D test target we designed mimics the USAF1951 test target. As shown in Fig.1, it has two parts: one is lateral resolution test target; the other is axial resolution test target. The lateral resolution test target is very similar to the USAF1951test target. For the lateral resolution test target, it has 6 groups, and each group includes three vertical and horizontal bars. All the bars are of the same height but differing in bar width according to their group number. For the axial resolution test target, it is comprised of six bars with different height profiles.



(a) (b)

Figure 1: Schematic of the 3D test target, (a) is the overall design picture; (b) is the size and structure

2.2 Fabrication

3D printing technique, rapidly developed in recent years, is a process of making a three-dimensional solid object of virtually any shape from a digital model. It is achieved by use of additive process, where successive layers of material are laid down in different shapes. It can be divided into 4 types according to their different principles: FDM (Fused Deposition Modeling), SLA (Stereolithography), SLS (Selective Laser Sintering), and PP (Plaster-based 3D Printing). Because of the special 3D structure construction which could hardly be done by traditional micromachining technology, we employed SLA 3D Printing technique to fabricate the 3D test target. The operating principle is displayed in Fig.2, and it produces one layer at a time by curing a Photo-reactive resin with a UV laser or another similar power source.

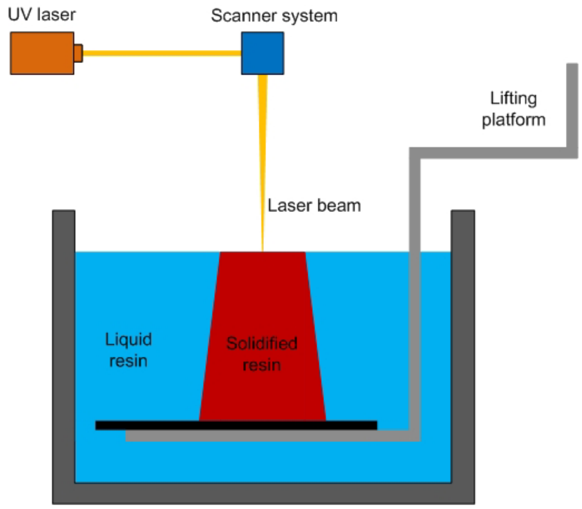


Figure 2: Schematic of the SLA (stereolithography) technique

For the fabrication process, firstly we designed 3D test target frame diagram with Solidworks software; secondly, the prepared 3D drawing file was imported into the SLA equipment (OBJECT Eden 260 from Stratasys Ltd, layer thickness: horizontal build layers down to 16um); subsequently, the photopolymer material was added; finally we could obtain the 3D test target.

3. OCT SYSTEM CONFIGURATION

A spectral domain OCT system as shown in Fig.3 was employed to acquire images of the 3D test target. The Telesto OCT system is operating at a central wavelength of 1310nm and has a large bandwidth of about 170nm by combing two SLD light sources. Another feature of this OCT lies in the camera which can real-time display the imaging area and offer a convenient observation. Its axial resolution is 6.5µm in air and 4.9µm in water, Lateral resolution（when scanning objective lens LSM 03 was used）is 13µm. Synthesis of the light source hits triple prism through circulator and is then reflected into beam splitting lens (BSL), dividing into 2 beams of Reference beam and Sample beam. The intensity of the Reference beam could be changed by adjusting the variable aperture (VA), while the optical path difference (OPD) could be altered by moving the reflecting reference mirror. The Sample beam goes through a pair of galvanometers and then passes objective lens before shooting the sample. The returning interference light enters spectrograph through circulator and the OCT images could be obtained after computer processing.

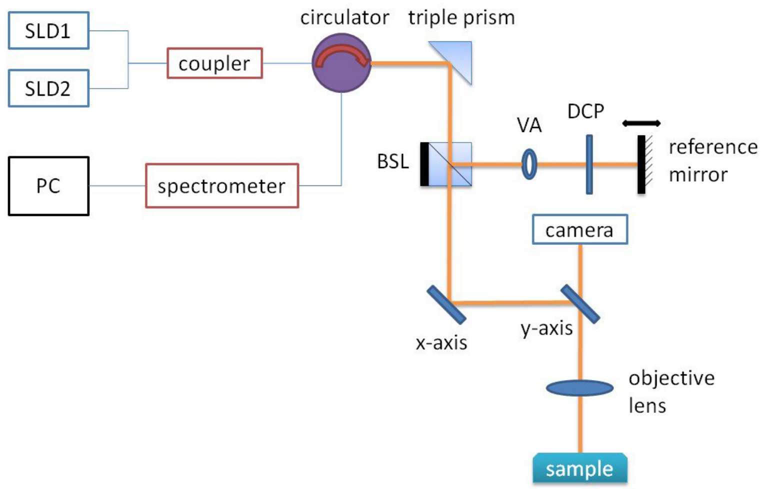


Figure 3: Configuration of the Telesto OCT system. VA: variable aperture; DCP: dispersion compensation plate; BSL: beam splitting lens.

4. RESULTS

4.1 Optical microscope measurements

For a better comparison, firstly we measure the 3D test target with optical microscope to check it. As displayed in Fig.4, the upper 3 pictures are the lateral resolution test target images. We can see group 2 and group 3 clearly, and the bar width was measured respectively. The bar widths of group 2 and 3 are 335 um and 228 um respectively. The lower 2 graphs show enface images of the axial resolution test target.

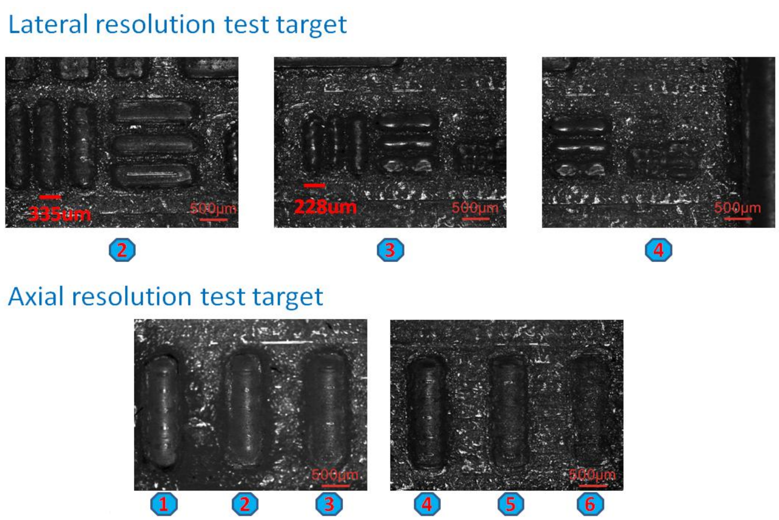


Figure 4: optical microscopic images of 3D test target

4.2 Probe surface profiler measurements

For the axial resolution test target, we measured their heights with a probe surface profiler. Apart from group 6, the deviations between measurement results and their design value are not that large and should be acceptable.

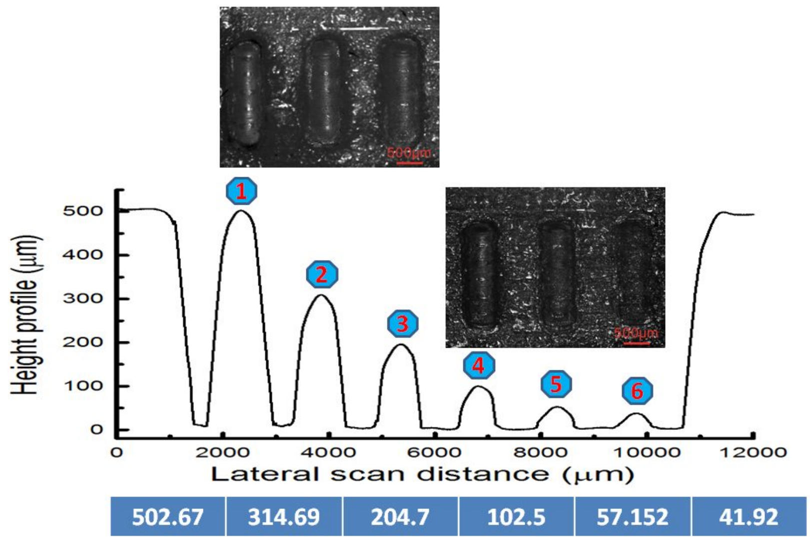


Figure 5: Height profile of axial resolution test target image taken by probe surface profiler.

4.2 OCT measurements

Fig.6 shows the OCT measurement results. The upper two pictures are the C-scan OCT images of the lateral resolution test target. The bar width of group 2 is 368 um and group 3 is 290 um. Similar to the microscopic images, group 4 and 5 can't be seen clearly because of limited resolution of the 3D printing fabrication. This lower picture is the B-scan OCT image of axial resolution test target. From Fig.6 we can clearly see the cross-section images of the axial resolution bars. And their heights were measured with the OCT system. It should be admitted that the OCT measurement results were not in agree with the results from optical microscope. There can be several reasons: (1) when we used the OCT system to measure the height, refractive index of the polymer material needs to be input. Currently, we use 1.5 as its index number. However, we needs to find out the real index value through further experiment; (2)When we measured the height from the OCT image, different results could be obtained with different edge extraction algorithms. You can see from the OCT image, the image edge contrast is not sharp and that could also affect the final result; (3)Finally, possibly the most important, the OCT system are directly provided by the manufacturer and it might has not been verified or calibrated accurately. That is also our main research purpose to design the 3D resolution test target. The traditional measuring optical microscope and probe surface profiler we used are calibrated, so we could use their measurement results as standard reference, and the OCT system is going to be verified and calibrated.

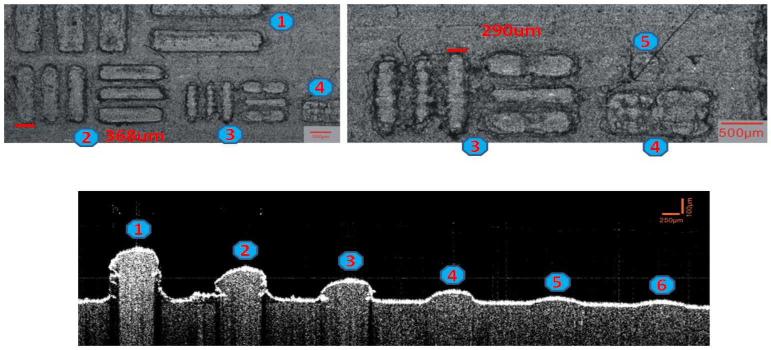


Figure 6: OCT measurement image of 3D test target

5. CONCLUSIONS

In this paper, we design and fabricate a new type of 3D test target which can be used in OCT resolution evaluation. It is featured with the following advantages: 1. the use of 3D print technique simplify production process and make it time-efficient; 2. its special design unites the lateral and axial resolution measurement of OCT, which makes much convenience for OCT resolution evaluation. We use optical microscope and probe surface profiler to have a comparison measurement and analysis toward 3D test target.

For the future work, improving OCT imaging measurement and analysis which includes improving image edge extraction algorithm and index measurement of 3D resolution test target will be firstly implemented. Secondly, the fabrication process of the 3D resolution test target could be considered to be upgraded. Last but not the least, image resolution capability of the OCT system is going to be verified with the 3D resolution test target

Acknowledgement

The research was supported by National Key Technology R&D Program of China (2011BAI02B02).

REFERENCES

[1] Huang, D. et al., "Optical coherence tomography," Science 254, 1178-1181 (1991).

[2] Fujimoto, J. "Optical coherence tomography for ultrahigh resolution in vivo imaging," Nature biotechnology 21(11), 1361-1367(2003).

[3] Agrawal, A., Pfefer, T. J., Gilani, N. and Drezek, R., "Three dimensional characterization of optical coherence tomography point spread functions with a nano particle-embedded phantom," Opt. Lett. 35, 2269–2271 (2010).

[4] Avanaki, M. R. N., Podoleanu, A. G., Price, M. C., Corr, S. A. and Hojjatoleslami, S. A., "Two applications of solid phantoms in performance assessment of optical coherence tomography Systems," APPLIED OPTICS52(29),7054-7061(2013)

[5] Tomlins, P. H., Ferguson, R. A., Hart, C. and Woolliams, P. D., “Point-Spread Function Phantoms for Optical Coherence Tomography,” National Physical Labratorary (NPL) report (2009).

[6] Lamouche, G., Kennedy, B.F., Kennedy, K. M., Bisaillon, C. E., Curatolo, A., Campbell, G., Pazos, V. and Sampson, D. D., "Review of tissue simulating phantoms with controllable optical, mechanical and structural properties for use in optical coherence tomography," Biomed. Opt. Express 3, 1381–1398(2012).

[7] Gu, R. Y., Lurie, K. L., Pipes, M. and Ellerbee, A. K., “Variable-sized bar targets for characterizing three-dimensional resolution in OCT,” Biomed. Opt. Express 3(9), 2317–2325(2012).

[8] de Bruin,D.M., Bremmer,R.H., Kodach,V.M., de Kinkelder, R., van Marle, J., van Leeuwen, T. G. and Faber, D. J., "Optical phantoms of varying geometry based on thin building blocks with controlled optical properties," J. Biomed. Opt. 15, 025001(2010).

[9] Agrawal, A., Chang, R., Connors, M., Stafford, C., Hwang, J. and Pfefer, T. J., “System-independent assessment of OCT axial resolution with a “bar chart” phantom,” Proc. SPIE 7906, 79060R (2011).

[10] Chang, R. C., Johnson, P., Stafford, C. M. and Hwang, J., “Fabrication and characterization of a multilayered optical tissue model with embedded scattering microspheres in polymeric materials,” Biomed. Opt. Express 3(6), 1326–1339 (2012).

[11] Curatolo, A., Kennedy, B. F. and Sampson, D. D., “Structured three-dimensional optical phantom for optical coherence tomography,” Opt. Express 19(20), 19480–19485 (2011).