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Seminar Paper Critical Review

Adeel Ahmad, Steven G. Adie, Eric J. Chaney, Utkarsh Sharma, and Stephen A. Boppart, "Cross-correlation-based image acquisition technique for manually-scanned optical coherence tomography," Opt. Express **17**, 8125-8136 (2009)  <http://www.opticsinfobase.org/oe/abstract.cfm?URI=oe-17-10-8125>

**Introduction**

Optical coherence tomography (OCT) provides real-time, high-resolution information about microscopic tissue structure, making it useful for presenting information to surgeons during time-sensitive procedures. Furthermore, it can be incorporated into microsurgical tools, lending it great potential for use in minimally invasive procedures. However, the success of OCT in the OR partly relies on utilizing OCT and presenting the data in a way that is useful to the surgeon.

Without processing, OCT probes return an A-scan history, or an image formed from sequential A-scans appended together. In order to obtain anatomically correct cross-sectional images, the OCT probe has been used in conjunction with a mechanical arm or stage that moves the sample at a fixed velocity for the duration of the scan. However, this is impractical for many surgical scenarios. Another approach is to use a computer-controlled galvanometer system to track the lateral motion of the beam, although the galvanometer has a very limited angular range, posing restrictions on the length of the lateral OCT scan. Therefore, while these existing methods of OCT image acquisition have their merits, they are not ideally suited to surgeons’ needs. It would be preferable to use simpler, hand-held manual probes, which allow for greater freedom of movement and control.

The purpose of the paper by Ahmad et al. is to introduce a method for OCT data processing that facilitates manual probe scanning. Since manual lateral scanning occurs with variable scan velocity, the constant sampling rate of the OCT probe is applied non-uniformly over the scan path. This results in an A-scan history that is a warped representation of the scan surface. The authors developed an algorithm for correcting for this distortion based on the degree of correlation between successive A-scans. The OCT scans in this study were taken on planar samples, by keeping the OCT probe orientation constant, such that the A-scans obtained were structured.

**Summary**

*Method*

The image acquisition algorithm presented in the methods section of the paper is mathematically straightforward and computationally inexpensive. The first A-scan from the complete set of A-scans obtained from an OCT scan is selected to be the first reference A-scan. The algorithm iteratively steps through each subsequent A-scan and assesses the correlation between the current A-scan and the reference. This correlation is quantified by the Pearson cross-correlation coefficient, which is essentially a scaled covariance between the intensity at corresponding points in each A-scan. Once the cross-correlation coefficient is computed, it is compared to a threshold value. If the coefficient is less than the threshold value, the current A-scan is deemed sufficiently distinct from the reference and is appended to the set of A-scans used to assemble the dewarped image. The reference A-scan is updated to the last appended A-scan, and the algorithm continues until all the A-scans have either been appended to the image or discarded as redundant.

The algorithm described by the authors is based on the idea that spatially immediate A-scans will be nearly identical, while spatially distant A-scans will not correlate with each other as closely. The validity of this assumption depends on the nature of the surface. For instance, if a surface includes a stretch of highly uniform topography, then the correlation between successive A-scans does not drop off as rapidly with distance as expected. This results in the algorithm mistaking the uniform stretch for a pause in probe movement, and the uniform stretch is thus omitted from the assembled image. This was indeed observed by the authors for the plasticine surface sample images.

To assess the quality of the assembled images, the authors aligned a computer-controlled translational stage and a manually movable stage such that both could be used to obtain OCT images of the same cross-sectional planes in a sample. The computer-controlled stage was used to generate uniformly scanned images against which the assembled, manually scanned images were compared.

**Assessment**

*Positive Aspects*

The paper is one of the first to use acquired OCT data from manual scans to form motion-compensated images. As such, it provides a simple method for discarding redundant A-scans arising from abrupt stops. The assembled images obtained for the samples tested closely agreed with the uniform scan images. This was true for a wide range of samples, including a silicone phantom, plasticine and various types of human tissue, indicating that the results of this method are very encouraging.

*Criticisms*

While the algorithm used to select A-scans is clearly described, the other sections of the paper offer less detail to the reader. In particular, the authors mention pre-processing the A-scans by applying a moving average filter and truncating A-scans to include only the parts containing sample information. The details of these steps are regrettably omitted, although they have great bearing on the validity and applicability of the technique.

*Improvements*

One of the proposed advantages of this technique is that it allows surgeons to use hand-held probes and tools for OCT imaging, thereby avoiding the inconvenience of bulkier probes with incorporated lateral scanners or external reference markers for tracking. However, variations in the angular orientation of the OCT probe cause the algorithm described in this paper to perform poorly. That is, there is still a significant restriction in the allowed motions of the tool relative to the surface. This would be a minor issue for lateral plane tissues, such as the ones used in the experiments conducted for this study. However, in the case of intraocular microsurgery, the curvature of the retinal surface would likely lead to poor performance of this technique unless scan paths were limited to small, approximately planar regions. The authors propose the use of a depth-dependent A-scan correlation to resolve this. They also mention that using a low moving-average filter to pre-process the A-scans could make the decorrelation curves less sensitive to slowly varying sample structure.

The authors do not outline a quantifiable measure of similarity between the uniformly scanned images and the assembled images. Although a visual comparison is powerful and relevant for applications in visualization of OCT B-scan sections, it is arbitrary at best and misleading at worst. Rather than relying solely on visually comparing the two images, it would have been more satisfying to see an analysis of the discrepancies between the two images.

**Conclusions**

The paper is successful in that the assembled images from the manual scans agree with the constant-velocity scans, indicating that the proposed algorithm works well for the samples chose. Specifically, these samples were planar, so that it was possible to maintain the probe orientation with respect to the surface. This factor was vital to the success of this simple approach, because it produced structured A-scans that could be analyzed with little pre-processing. Therefore the proposed method could be suitable for imaging flat tissues with similar reflective and structural characteristics to the materials used here as surfaces. However, much more pre-processing is needed if this algorithm is to be applied to OCT scans of curved tissues, such as the retina.