33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Enhanced Video Images for Tympanic Membrane Characterization

Lin Cheng, Jinfeng Liu, Corrie E. Roehm and Tulio A. Valdez

Abstract — **The objective of this article is to introduce portable devices capable of providing video images of the tympanic membrane and tympanic cavity of the ear. Specifically, digital video otoscopy is introduced as an effective platform for tympanic membrane characterization. In addition, we show how digital image enhancement and segmentation processing techniques can be applied to the acquired images, which could provide more visual detail and objective clinical interpretation.**

I. Introduction

Otitis media, or middle ear inflammation, is a common condition affecting the pediatric population with high morbidity and frequency. It is estimated that direct and indirect medical costs associated with otitis media amount to 5 billion dollars annually in the United States [1-3]. Making the diagnosis for otitis media is challenging since the tympanic membrane is not easily visible due to its location in the external auditory canal, requiring the use of special devices for evaluation. Physicians rely on otoscopes in combination with a history of ear aches and fever to make the diagnosis of otitis media. As shown in Fig. 1, otitis media occurs in the middle ear, or tympanic cavity, behind the tympanic membrane. When an acute infection is present, the middle ear cavity is filled with purulent fluid which is thick and turbid in nature. The middle ear fluid and changes in vascularity and thickness of the tympanic membrane can be seen from the external auditory canal with an otoscope. Unfortunately, despite being the most important diagnostic tool, most of today's otoscopes consist of century-old technology relying on a basic light source and magnifying lens. The diagnosis still relies heavily on the interpretation of the image observed by the physicians' eyes through the lens.

In response to this observation, this paper aims to explore the potential capabilities of portable devices that can provide video images to ear cavities. Digital images extracted from videos make subsequent signal processing possible, which could provide more objective clinical interpretation. Enhancement filtering is used as a first step for image processing. Contrast-enhancing techniques and image manipulation for visualizing the physical properties of tissue may extend the diagnostic usefulness. In addition, image segmentation is introduced to isolate anatomic structures of interest.

This article is organized as follows: Section II outlines related work. Then, Section III describes the experimental apparatus. Section IV describes image processing techniques used in this study, together with experimental results in Section V. We conclude in Section VI.

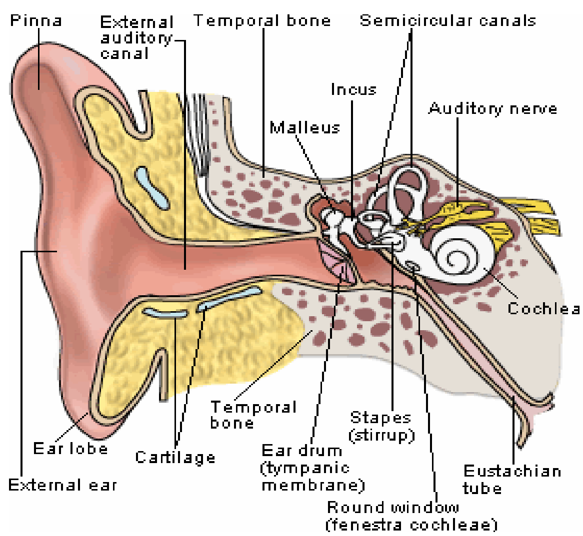

Fig. 1. Anatomy of the Ear [4].

II. Related Work

Standard pediatric evaluations for otitis media include a thorough clinical history combined with otologic examinations using otoscopes for visual inspection, pneumootoscopy to evaluate the mobility of the tympanic membrane, and adjunctive tests including tympanometry and audiograms [5,6]. Reliable diagnosis of otitis media is challenging, and the accuracy of these available methods has been shown to be lacking in specificity and consistency in both generalist and subspecialist settings [4, 5], with accurate diagnosis rates between 40-80% depending on the setting and reporting source [6,7]. A number of studies of both pediatric trainees and practitioners showed their otoscopic diagnostic skills to be limited. Pichichero, reported mean correct scores of only 41% among 383 pediatric residents and 51% among 2190 practicing in a test using 9 videotaped, otoendoscopically obtained examinations [7].

Several new technologies have been explored for their potential diagnostic utility – acoustic reflectometry [9],

Manuscript received April 15, 2011. This work was supported in part by a Surgical Research Foundation Grant from Connecticut Children's Medical Center and an FRC grant from Trinity College.

Lin Cheng is with the Department of Engineering, Trinity College, Hartford, CT, 06106 (e-mail: lin.cheng@trincoll.edu).

Jinfeng Liu is with Trinity College, Hartford, CT, 06106 (e-mail: Jinfeng.Liu@trincoll.edu).

Corrie E. Roehm is with University of Connecticut Health Center, Farmington, CT 06030 (e-mail: corrie.roehm@gmail.com).

Tulio A. Valdez is with the Department of Otolaryngology-Head and Neck Surgery, Connecticut Children's Medical Center, 282 Washington Street, Hartford, CT 06106 (e-mail: Tvaldez@ccmckids.org).

ultrasound evaluation [10], digital imaging, combined tympanometry/visual evaluation and acoustic tympanometry – with mixed results. Some of the newer technologies are poorly reproducible, difficult to complete in pediatric patients, or inaccurate. Video otoscopy is becoming more widely used and has been advocated as a training tool for pediatricians to improve their diagnostic abilities.

Fig. 2. Video otoscopy of normal volunteer.

III. Experimental Apparatus

Images were obtained with a CCD camera 1280 x 1024 Resolution, Color, USB 2.0 (Thorlabs - Newton, New Jersey) adapted to a standard otoscope (Welch Allyn W-A23820 Wa Macro-View Otoscope, Skaneateles Falls, NY) using a C–mount adapter. Approval from the IRB at Connecticut Children's Hospital was obtained to allow us to capture ear images in adult normal volunteers (as shown in Fig. 2). White light from a 3.5 volt halogen lamp (Welch Allyn, Skaneateles Falls, NY) incorporated into the otoscope was used as the source of illumination. Images were centered on the tympanic membrane using the malleus bone as a reference point to identify the mid-point of our image. The images were saved in bitmap format.

IV. Image Processing

The measurement apparatus and acquisition techniques provide a usable data format for digital image processing. We believe contrast-enhancing techniques and image manipulation for visualizing the physical properties of tissue may extend the diagnostic usefulness. One of the aims in ear examinations is to improve the definition of ear structures. Fine image details are often desirable for a more reliable diagnosis of middle ear conditions.

To this end, we perform image enhancement to make the image easier to visually examine and interpret by the physicians. We use the linear unsharp algorithms as the first step.

Linear unsharp algorithms obtain an enhanced image *E(m,n)* from the input video capture image *I(m,n)* as follows (*m* and *n* are row and column index for the matrix form representation of digital images)

$$E(m,n) = I(m,n) + \lambda C(m,n), \tag{1}$$

where *C(m,n)* is the correction signal computed as the output of a linear highpass filter and λ is a positive scaling factor that controls the level of contrast enhancement achieved at the output. We obtain *C(m,n)* by a convolution kernel to perform spatial filtering: an appropriately defined lowpass filter is employed first to produce the smoothed version of an image, which is then pixel subtracted from the original image in order to produce *C(m,n).*

During the tuning procedure, negative Laplacian kernel filters are often desirable owing to its simplicity. In our implementation, after convolving an original image with a discrete negative Laplacian kernel, it need only be scaled and then added to the original image. This discrete negative Laplacian kernel often needs to be fine tuned to adjust both its size and the approximating of the two-dimensional Laplacian operator shape [11].

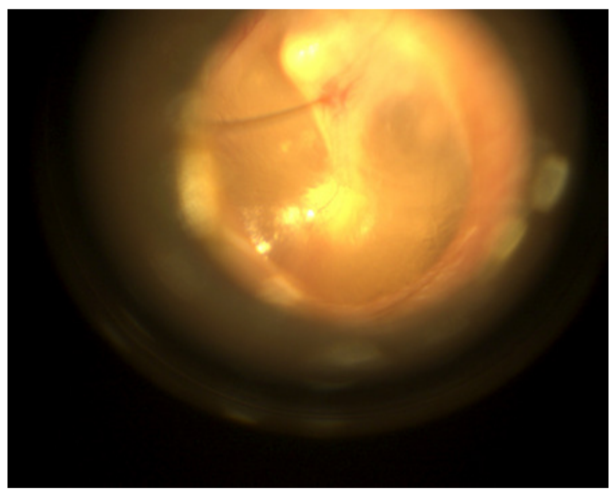

Fig. 3. Sample acquired image.

In addition to image enhancement, we also employ segmentation methods to identify and isolate the structured units. In particular, a continuity-based segmentation is used to look for the similarities or consistency in the search of structured bones in acquired images [12].

V. Results and Interpretation

Fig. 3 depicts a sample acquired image from video. Fig. 4 is the enhanced version using processing techniques described in Section IV. To be concrete (consistent?), for the image dimension of 1024 by 1280 pixels, we used a discrete negative Laplacian kernel of 10 pixels radius. The approximating factor of the two-dimensional Laplacian operator shape is set to be 0.9.

This image shows increase enhancement of the tympanic membrane and malleus vasculature. Tympanic membrane vascularity in the area of annulus and tympanic membrane can be an important marker in the presence of middle ear fluid and acute otitis media. More importantly the contrast between the vasculature and the surrounding tympanic membrane can be used for future algorithms for diagnosis of middle ear conditions.

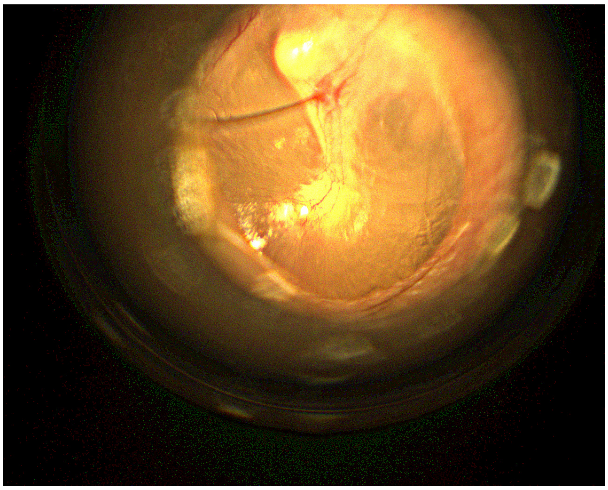

Fig. 4. Sample filtered image using an unsharp masking filter. .

While unsharp masking filters are simple and work well as a first step in these acquired images, it could suffer from a few drawbacks. First, the highpass operation step could make the system sensitive to noise. Second, it might produce overshooting artifacts in the output image, owing to the much greater enhancement to the high-contrast areas compared to the rest. We are currently exploring other image processing techniques to mitigate theses potential shortcomings.

Fig. 5. Acquired image with segmented malleus.

Fig. 5 depicts an acquired image with segmented malleus. The ability to selective identify areas of the tympanic membrane can help in the development of diagnostic algorithms by targeting different regions of the tympanic membrane with clinical significance such as position of the malleus, visibility of intratympanic structures, bulging of the tympanic membrane and vascularity in the region of the annulus.

VI. Conclusion

In this paper, we presented a portable video otoscopy platform that provides video imaging of the tympanic membrane and tympanic cavity of the ear. The proposed methodology complements the existing techniques for clinical analysis by providing more objective image characteristics into clinical evaluation. In addition, experimental results using digital image enhancement and segmentation show flexibility and promise for better diagnostic algorithms by targeting different regions of the tympanic membrane with clinical significance.

References

[1] Gates, Agency for Health Care Policy and Research, 1996.

[2] C. Bluestone and R. Rosenfeld, *Evidence-based otitis media.* PMPH USA; 2 edition (June 1, 2003).

[3] William W. Hay, Anthony R. Hayward, Myron J. Levin, Judith M. Sondheimer, *Current pediatric diagnosis & treatment*. Appleton & Lange, 1997.

[4] http://www.guadalupe-ec.org/CLINIC/ENT/Content/AnatomyEarNoseThroat.htm

[5] Blomgren K, Pitkaranta A. Current Challenges in Diagnosis of Acute Otitis Media. Int J Ped Otorhinolaryn 2005; 69:295-299.

[6] Takata GS, Chan LS, Morphew R, Mangione-Smith R, Morton SC, Shekelle P. Evidence Assessment of the Accuracy of Methods of Diagnosing Middle Ear Effusion in Children with Otitis Media with Effusion. Pediatrics 2003; 112:1379-1387.

[7] Pichichero ME. Assessing diagnostic accuracy of otitis media and tympanocentesis skills assessment among pediatricians. Eur J Clin Microbiol Infect Dis. 2003 Sep; 22(9):519-24. Epub 2003 Aug 21.

[8] Pichichero ME, Brixner DI. Rethinking the total cost of care in AOM and ABS: The impact of improved diagnostic accuracy and antibiotic treatment where high efficacy and adherence are achievable. Am J Manag Care. 2006 Aug;12(10 Suppl):S283-91.

[9] Chianese J, Hoberman A, Paradise JL, Colborn DK, Kearney D, Rockette HE, Kurs-Lasky M. Spectral gradient acoustic reflectometry compared with tympanometry in diagnosing middle ear effusion in children aged 6 to 24 months. Arch Pediatr Adolesc Med. 2007 Sep;161(9):884-8.

[10] Discolo CM, Byrd MC, Bates T, Hazony D, Lewandowski J, Koltai PJ. Ultrasonic detection of middle ear effusion: a preliminary study. Arch

Otolaryngol Head Neck Surg. 2004 Dec;130(12):1407-10.

[11] Polesel, A. and Ramponi, G. and Mathews, V.J. Image enhancement via adaptive unsharp masking. IEEE Transactions on Image Processing, 2000. 9(3): 505--510.

[12] Pham, D.L. and Xu, C. and Prince, J.L., Current Methods in Medical Image Segmentation, Annual review of biomedical engineering, 2000. 2(1): 315--337.