Comparison of Image Processing Techniques for Ear Canal Diameter Measurement

Mariaulpa Sahalan, Christina Pahl, Heamn Jabbari, Mohsen Marvi Baigi, Eko Supriyanto

***Abstract*—**Ear is one of the five important senses in our body which functions in detecting sounds and aiding in balance and body position. Early detection of the abnormalities and cancer of the ear plays an important role in its therapy. Computer tomography (CT) and Magnetic Resonance Imaging (MRI) are two common imaging modalities used to detect abnormalities of the ear. In this paper, we introduce the use of ultrasound imaging to measure the diameter of ear canal mainly to detect abnormalities and tumor in the outer ear. The objective is to compare different ultrasound ear image processing technique for ear canal diameter measurement. Image was processed using few different filtering technique and reconstruction method before using different edge detection method. The filtering techniques used are further compare for their mean square error and signal to noise ratio. Gaussian filter possess a lower MSE value which is 14.23 and highest signal to noise ratio which is 36.59. While, the best combination of method was tophat by reconstruction with canny edge detection which has shorter execution time which is 1.92 second and has good performance. The diameter of ear canal measured from image processing is approximately same with acceptable range of values 1.73% to 10.2% of original diameter measured directly from ultrasound.

Keywords*—Ear Cancer, Edge Detection, Image Reconstruction, Morphological, Tumor, Ultrasound Ear.*

I. Introduction

Anatomy of the ear

EAR is the organ which is a part in auditory system which functions in detecting sounds and aiding in balance and body position. Vertebrates have a pair of ears which placed symmetrically on opposite sides of the head and its function aids in the ability to localize sound sources [1].

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The human ear divided into three major parts. First is outer ear which consists of auricle and the external auditory canal. Sounds are guided and collected through the ear canal to the middle ear. The sound arrives at the eardrum which is a flexible, circular membrane which starts to vibrate when sound waves strike it. Second, is the middle ear which is an air-filled space separated by the eardrum tympanic membrane to the outer ear.

The movement of the eardrum to the middle ear is how the sound waves pass by. In the middle ear are three tiny bones: the malleus (hammer), incus (anvil) and stapes (stirrup) which are collectively known as the ossicular chain. These form a bridge from the eardrum to another membrane at the entrance to the inner ear and their interaction increases and amplify the sound vibrations further before these are relayed fully into the inner part of ear through the oval window. Lastly is the inner ear and it referred to as the cochlea which is similar in shape to a snail shell [2]. It consists of several membranous sections which are filled with watery fluids. Computer tomography (CT) and Magnetic Resonance Imaging (MRI) are two common imaging modalities used to detect abnormalities of the ear.

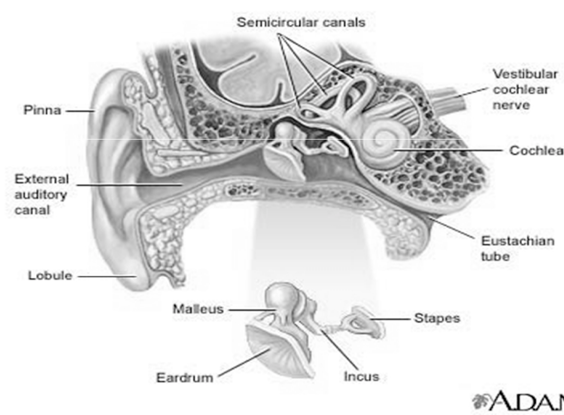


Fig . 1 External auditory canal or ear canal [18]

Cancer and Abnormalities of the outer ear

Cancer in the ear can happen in the outer ear, middle ear and inner ear. Causes for the middle ear cancers remain unknown but cancers of the outer ear usually develop in the skin of the ear due to long term exposure to hot sun. Ear cancers are in the form of tumors and abnormal growth and can be observed both in the inner ear and on the outer ear [2]. Squamous cell carcinoma is the medical term for these cancerous cells. Tumors in different areas of the ear behave differently, therefore the type of ear cancer or tumors depends on the location whether in outer ear, middle ear or inner ear. Furthermore, tumors of the ear can be malignant or benign.The only way to confirm the diagnosis of the ear is through biopsy which is taking a small amount of tissue from the abnormal area of the ear and examining it under a microscope.

The common problems in the outer ear include blockages in the external ear canal, otitis externa, which is the inflammation of the ear canal, which are frequently found among swimmers ear and perforated ear drum [2] objects found in ears include food material, beads, toys, and insects.

Besides, diagnostic imaging techniques (conventional radiography, computed tomography and magnetic resonance imaging) are an essential tool in the diagnostic work-up of ear diseases [4]. Conventional radiography such as X-ray is commonly used, but often lacks sensitivity. Therefore, advanced modalities such as computed tomography (CT) and magnetic resonance (MR) are complementary imaging studies of the middle ear, labyrinth, internal auditory canal and their contents. CT provides excellent images for bony structures and is indicated where osseous changes are of greatest diagnostic importance [2]. MR which is more advanced than CT is superior in imaging soft tissue components including intral-abyrinthine fluid [5]. This exceeds far beyond those of CT scanning and ultrasound. But it has trouble dealing with patients with pacemaker and metal implants. Furthermore, MRI may have effects on the cardiac field. Finally, it is a uncomfortable and expensive technique [19]]. Therefore, more than one of these imaging techniques may be required in order to make a detail diagnosis.

Medical Sonography

Medical sonography also known as ultrasonography which is a ultrasound-based diagnostic imaging technique used for visualizing subcutaneous body structures including tendons, muscles, joints, vessels and internal organs for possible pathology [7]. Obstetric sonography is commonly used during pregnancy. Ultrasound waves refers to acoustical waves above human hearing (f>20 kHz). First of all, only a specific range of high frequency sound waves is usable for imaging. Basically, Ultrasound devices operate with frequencies from 20 kHz up to several gigahertz Lower ranges of ultrasound frequencies can be used for medical destruction of kidney stones whereas higher ones from 1MHz to 5Mhz are used for imaging in humans. Whether or not, the sound pulses are foreseen to image or break objects, they need to be transmitted into the body using a task conforming probe. The waves then penetrate the tissues and hit boundaries between fluid, bones and soft tissue. [19]

Medical imaging technique that we use in this study uses ultrasound enhanced by the Doppler effects. Doppler effects is the change in the observed frequency of an acoustic or electromagnetic waves due to relative motion of the source and receiver. When sounds is emitted as a constant by an object and a recipient is moving forward or backward from the source, a change in frequency occur which is called the Doppler Effect. The difference between the original frequency and the moving target is demodulated and manipulated to show either an image or graph.

Comparisons among Medical Modalities

Each modalities including CT scan, MRI and ultrasound are using different principles to generate an image for diagnostic purpose ,thus each of the image have differences[2][4].

Table 1: Comparisons of Ultrasound and CT scan [5,7,8]

Features	Ultrasound	CT Scan
Resolution Status	Poor resolution for the ear scanning and may be good if using higher frequency probe such as 6.5 MHz	Have a high contrast resolution for the ear scanning.
Principle used in imaging	Uses high frequency sound wave	Uses X-ray beam
Details of part	Ultrasound not usually used for bony structure but internal organs of the body such as kidney, liver and others.	Provides better information about bony structure.
Medical Application	Used for diagnostic applications such as visualizing fetuses, internal organ structure for determine its size or structure.	Used for screening disease such as colon cancer (cancer detection), bone injuries, abnormalities in the head, chest and so on.
Radiation Exposure	No radiation will expose to patient as it only used sound wave.	Patient is exposing to moderate high radiation as it used X-ray.
Advantages		Remove superimposition of structures other than the region of interest.
Disadvantages		Risk of causing cancer.

After comparing the pros and cons of ultrasound and CT scan, there are one modality which is MRI posses the advantages of ultrasound and CT scan. MRI uses the magnetic field and pulses of radio wave energy instead of using ionizing radiation like CT scan [5]. MRI can provide a better contrast between the different soft tissues of the body and it is more safety compared to CT scan in term of the radiation exposure to patient some more have more clearly diagnose image compare to ultrasound [6]. Unfortunately, some patients might be aware of the radiation caused by CT scan and some are reluctant to be examined using MRI due to claustrophobia.

The objective of this study are to introduce an alternative image acquisition of ear canal image using Ultrasound modalities and to compare different ultrasound ear image processing technique for ear canal diameter measurement.

II. Materials and Methods

In our study we used the Toshiba Aplio MX Doppler Ultrasound to scan our ear. The transducer we used for our study is transducer with frequency 3.5MHz. It was expected that transducer with frequency 6.5MHz will give us better image due to better angulations and resolution but the transducer was in repair.

Three types of transducers, 6.5 MHz, linear, 3.5 MHz also curvilinear, and 8MHz linear probe on 4 subjects to demonstrate the most clear image, and most accurate in diagnosis we used power color Doppler (PCD) technique to guide us to the canal exactly also to detect the surrounding blood vessels, during the scan we found that by scanning different types of transducers in females are most easy to detect than male subjects, the reason behind this is the situation of the mastoid process which is in male some closer to the mandibular condyle and more protrude than female, so that the positioning of the probe in female is more simple since we can use the wider space between the condyle and the mastoid bones as a window to input the ultrasound beam toward the ear canal .

The scanning techniques which used in this study are scanning in sagital axis with some angulation posteroanteriorly in some times, and in coronal or transverse scan without angulation. We also used power color Doppler to detect the major arteries and veins around the area of interest.

The patient can be in supine or sitting position, as it is comfortable to the patient the probe placed on the space between the mandibular condyle and the mastoid process inferior angle.

A. Raw Material (Input images)

Three input images used for diameter measurement are displayed below. All images were taken by the same ultrasound machine and the same sonographer. this study, totally three input images are used for diameter measurement and 1 image is used for method testing. The figures below shown are examples of the original ultrasound images which are used for further image processing.

Fig 2: Ultrasound image of ear canal with 6mm diameter using 3.5MHz transducer .Measurement was performed manually.

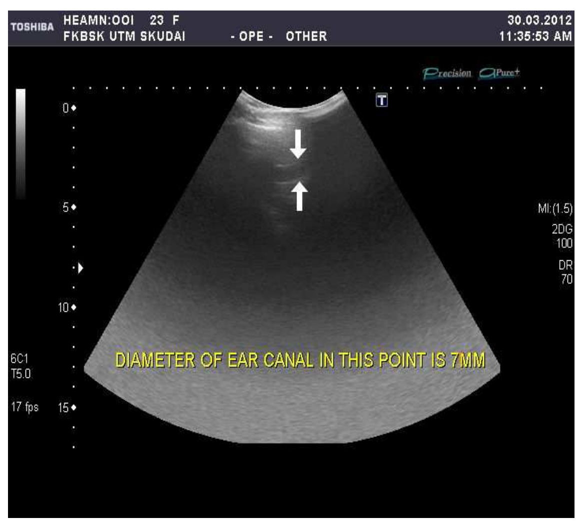


Fig 3: Ultrasound image of ear canal with 7mm diameter using 3.5MHz transducer . Measurement was performed manually.

Fig 4: Ultrasound image of ear canal with 8mm diameter using 3.5MHz transducer . Measurement was performed manually.

Fig 2, Fig. 3 and Fig. 4 above shows different part of ear canal which their diameters measured range from 5mm to 8mm. These deviations are caused by the varying positions of measurement. In Fig. 3 we can see a diameter with the legth of 8mm. This is the maximum value found in at same probe of 3.5MHz. It shows that, the ear canal is not equal in diameter along the length of the canal. The diameter of ear canal is varied from 5mm to 8mm.

B. Flow Chart of Image Processing

Three input images were taken as input for the image processing part Image cropping was performed to acquire only the ear canal section. As it can be obtained in Fig. 1 to Fig. 3, the ear canal is just a small part of the ear displayed in the ultrasound image.Therefore, region of interest (ROI) is selected for every image in order to save the computational time and minimized the noise that may be appeared in the image. to suit some objective criteria.

Various Filtering methods are applied to the input images to eliminate noise. After that, output image based on performance was chosen for further image processing. They Among them are averaging filter, circular averaging filter, Gaussian filter, 2D median filter and wiener filter. Averaging filter perform its function by replacing each pixel by the average of pixels in a square window surrounding this pixel.

This averaging filter trade-off between noise removal and detail preserving with large window can remove noise more effectively but also blur the edges or details of the image. Besides, Gaussian filter is a 2D convolution operator that is used to blur images and remove noise and detail. It is similar to mean filter but uses a different kernel. The degree of Gaussian smoothing is determined by the standard deviation of the Gaussian. While median filter is taking the median value instead of the average the pixels in the window. Besides, the window shapes does not need to be a square and special shapes can preserve line structures. Wiener filter is based on statistical approach and executes an optimal tradeoff between noise smoothing and inverse filtering

Some image reconstruction methods which are were used are Tophat by reconstruction, opening by reconstruction with small horizontal line and final reconstruction. Reconstruction methods involveis the morphological transformation. Here, two images,one acts as a marker and the other as a mask, constrain the transformation. It also retrieves the information that may be lost during the image transformation process [14].

After performing filtering, edge detector is applied to find the edge of the part. The edge detection methods are Canny, Laplacian, Sobel and Prewitt. The edge detection can determined the boundary of the desired part in the image but also preserves the structural properties of the image. Comparison on the quality of the image different filtering and image reconstruction method and the edge detection method was performed. Results for ear canal diameter using image processing techniques are compared with using direct measurement from ultrasound machine [11].

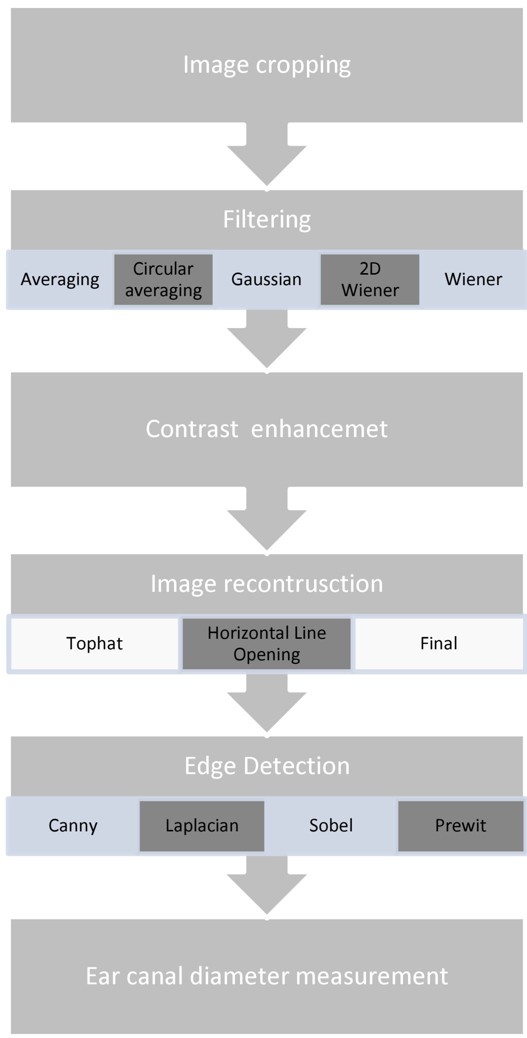


Fig 6: Process of Image Processing

III. Result and Discussion

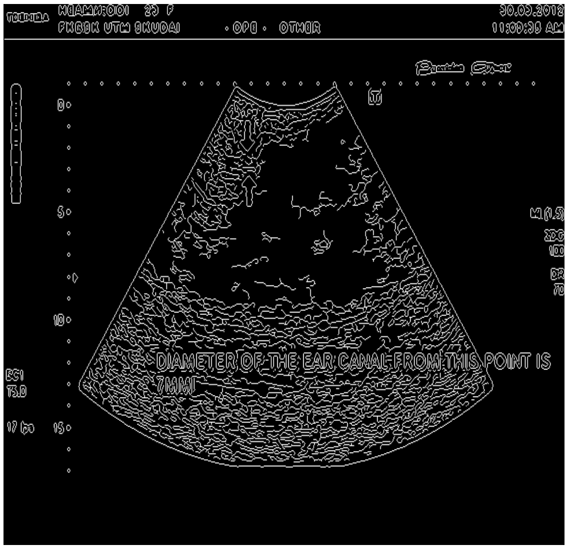


Fig 11: Original Image with edge detection method

The figure above is the original image which undergoes the edge detection process. The image is too large for analysis purpose because the ear part in the image is only the small portion. Therefore, image cropping is necessary to save the computational time and increase the image processing efficiency.

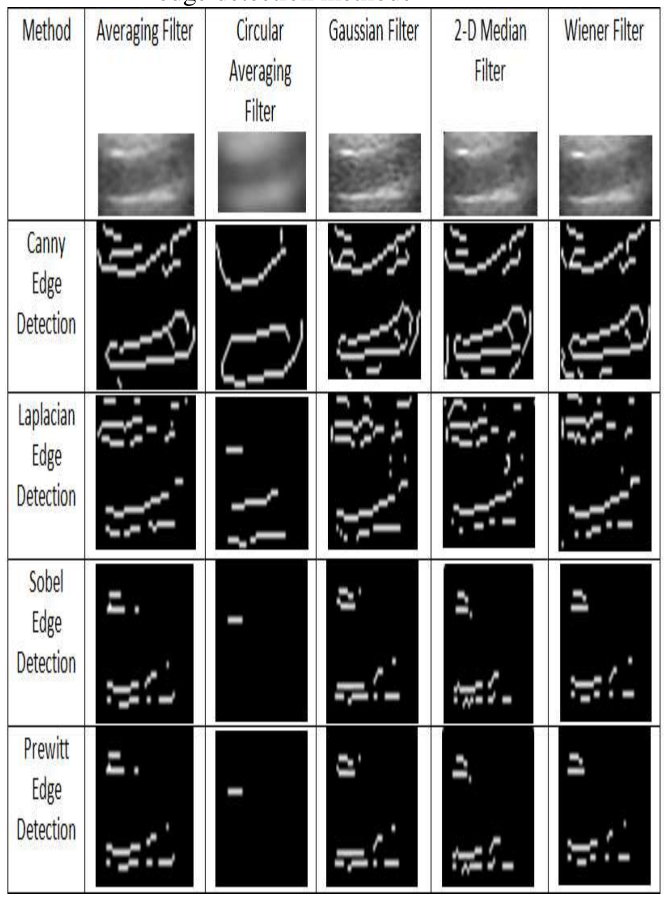
However, the input images are undergoing the contrast enhancement before further image processing. The purpose of image enhancement is to improve the appearance of an image. Then image cropping is performed to reduce the computational time and reduce the unwanted information after confirming the desired part of ear canal [12].

A. *Filtering and Edge Detection Methods*

There are some filtering method is applied to the input image to determine the best method for further image processing. There are averaging filter, circular averaging filter, Gaussian filter, 2D median filter and wiener filter. The purpose of filtering is to eliminate the possible noise appeared in the image. While the edge detection methods are Canny, Laplacian, Sobel and Prewitt [17].After performing the filtering technique, edge detector is applied to find the edge of the part and its purpose is to identify the boundary of the required part by significantly reducing the amount of data but preserving the structural properties to be used for further image processing. Edge detection of all four types was performed and the canny shows the best results which expected as canny edge detection accounts for regions in an image. Although it is more expensive if compared to other types of edge detection method, however the canny edge detection algorithm performs best under almost kind of scenarios [15].

The table 2 below shows the comparison of every filter and every edge detection methods [13].

Table 2: Comparisons of five filtering methods with four edge detection methods



From the table 3 below, mean square error and signal to noise ratio for every filtering methods are calculated between the original image and filtered image. MSE should be less and PSNR should be higher for better quality of image. Therefore, Gaussian fitler possess a lower MSE and higher PSNR among the five filtering methods which are 14.2336 and 36.5977 respectively.

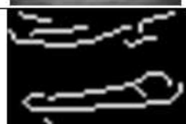
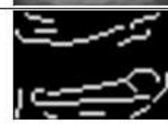
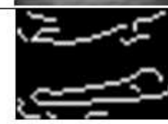
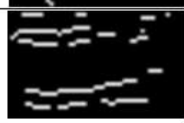
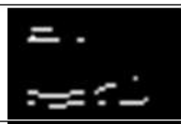
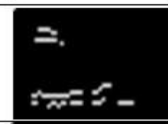
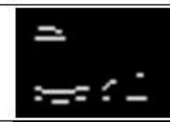
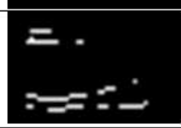
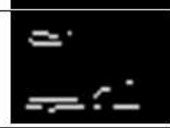
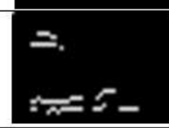
Table 3: Comparison of MSE and PSNR for every filtering methods

	Mean Square Error (MSE)	Signal to noise ratio (PSNR)
Averaging Filter	120.5185	27.3203
Circular Averaging Filter	417.5306	21.9239
Gaussian Filter	14.2336	36.5977
2-D Median Filter	117.9204	27.4149
Wiener Filter	97.4787	28.2417

B. Image Reconstruction and Edge Detection Methods

Besides, image reconstruction also performed before the edge detection method. There are some reconstruction method which are Tophat by reconstruction, opening by reconstruction with small horizontal line and final reconstruction.The result is shown in table 4. Its purpose of edge detection is to retrieve image information that may be lost in the process of image formation[15].

Table 4: Comparisons of reconstruction methods with four edge detection methods.

Method	Averaging Filter	Circular Averaging Filter	Gaussian Filter	2-D Median Filter	Wiener Filter
					
Canny Edge Detection					
Laplacian Edge Detection					
Sobel Edge Detection					
Prewitt Edge Detection					

C. Comparisons of the Two Best Methods

Despite that, comparison are made base on execution time and the complexity of the method too. The best method found from table 2 was Gaussian filtering following with canny edge detection while tophat by reconstruction method with canny edge detection was choose from table 4.

Edge detection result which has the less noise and also has better visualization in terms of its probability of detecting real edge points is higher while the probability of falsely detecting the non-edge points is lower. Thus, canny edge detector possesses these properties. Meanwhile, the computational time is important for the image processing to indicate their efficiency.

Besides, the complexity of both methods selected also compared. For Gaussian filter, reconstruction involved several step to perform its task such as before tophat-by-reconstruction, opening-by reconstruction need to be performed that indicate image is undergoing two step of preprocessing method before edge detection. Therefore, the complexity is higher for tophat-by-reconstruction.

The final decision of the best method is tophat by reconstruction with canny edge detection which it has shorter execution time and has good performance.

Table 5: Comparisons of Two Best Methods

	Gaussian Filter	Tophat-by-reconstruction
Canny Edge Detector		
Execution time	2.246223 s	1.922528 s
Complexity	$G(x,y)=\frac{1}{2\pi\sigma^2}e^{\frac{x^2+y^2}{2\sigma^2}}$	$\gamma_g^R(f)=R_g^\delta g(\varepsilon_g^n(f))$, $RWTH(f)=f-\gamma_g^R(f)$

Where x is the distance from the origin in the horizontal axis, y is the distance from the origin in the vertical axis and σ is the standard deviation of the Gaussian distribution. While for the tophat by reconstruction, *f* is the function of tophat or input image, g is the result, δ is dilation, ε is erosion. Tophat by reconstruction method is dependent of other function before it applied to the image.

D. Comparisons of Diameter of Ear Canal

Totally 7 images are selected for the diameter measurement using image processing to compare with the value directly measured from ultrasound. The results from image processing are approximately same with the direct results measured from ultrasound as shown in table 6.It fulfill the standard diameter range of an adult which is 5mm to 11mm. Besides, the error percentage of the measured value can negotiate with the values measured by ultrasound is 1.73% to 10.2%.

This condition indicates that the diameter measured by image processing method may vary between the ranges shown in table below for every part of ear canal. For medical point of view, the diameter of ear canal will increase from the inner part to outermost part.

Results obtained from the present study indicated that diameter measured by using various transducers shows similar results for right and left ear canals in same individual. It has been reported that measurement of ear canal diameter shows significant differences between male and female.

Different types of probes or transducer which have been used in this study were 3.5, 8 and 6.5 megahertz (MHz), that first two (3.5 and 8 MHz) are limited by some drawbacks. For instances, the image produced by 3.5 MHz transducer, which is a curvilinear probe, is small and there is a need to magnify the image to overcome this problem and have clearer and better image. The image obtained from 8 MHz transducer is not clear enough as well. Increasing the depth of the beam which closes the edge line of the ear canal has to be done to solve the problem.

Best resolution of image was observed from the images taken by 6.5 MHz transducer which is a linear one. Images observed from female subjects were clearer than male ones since in males the mastoid process is closer to candyle compare to females.

It can be said that, Images obtained by ultrasound from ear canal were clear, particularly by using 6.5 MHz transducer. Thus, this experiment proves that statement and the difference is only the diameter is only the diameter value as every human in terms of gender and age is unique.

Table 6: Ear Canal Diameter comparisons

	Canny Edge Detection after tophat by reconstruction	Diameter Measured From Ultrasound	Diameter Measured by Image Processing	Error percentage
Image 1		5mm	4.4921mm	5mm±10.2%
Image 2		6mm	5.8448mm	6mm±2.69%
Image 3		6mm	5.5625mm	6mm±7.29%
Image 4		7mm	6.5160mm	7mm±6.91%
Image 5		7mm	6.8792mm	7mm±1.73%
Image 6		8mm	7.5453mm	8mm±5.68%
Image 7		8mm	7.2217mm	8mm±9.73%

IV. Conclusion

In conclusion, a method of image reconstruction followed by canny edge detection is performed for ultrasound image processing after comparison with several methods. Besides, through the image processing, the diameter of ear canal for different part of ear canal is measured and the results obtained are approximately same with the results measured by ultrasound by the error percentage for every images is in the range of 1.73% to 10.2%. Although this error is not absolutely reliable, the diameter measured from both ultrasound and image processing method is in the range of an adult's ear canal diameter. This application may used for tumor detection at ear canal as if have the tumor grow along the ear canal, the diameter will definitely not same with the normal ear diameter range. For future works, the automatic diameter measurement from image processing method can obtained by directly point out the distances from the image.

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