Experimentation of Measuring Three Dimensional Ultrasound Resolution

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***Abstract*— The quantification of the ultrasound images requires resolution of the ultrasound probe and image knowledge. However, only little information are available for ultrasound resolution where most of the publications used the physical information (frequency, band width and velocity of sound in tissue) to estimate the resolution. In this work, the experiment has been conducted to estimate the real size of objects acquired by three dimensional ultrasound imaging system. Then the predicated resolution has been used as a factor to measure heart ventricle stroke volume acquired using real time 3D echocardiography imaging system (ie33 Philips, X7-2t transducer) with the absence of the probe's physical information. Results: the results were validated by experts and the successful rates were acceptable with high accuracy. The finding of this experiment is useful for the researchers, where they can estimate the real size of any object (organ) acquired by 3D ultrasound X7-2t transducer, as it used as tool in our research to measure the ventricle volume.**

Index Terms— Echocardiography, Right Ventricle, Stroke Volume, Matrix Array Transducer, Ultrasound

I. INTRODUCTION

THE medical advantages of ultrasound are visualizing the human organs for clinical reports, pre-operation planning, and dissection making [3].

In additional to the ability of quantifying imaged region of interest (ROI) by measuring it's dimensions, area, volume and velocity [9] and [6]. Besides its other advantages, ultrasound imaging can also assist medical specialists in their clinical work. Along with all the developments in the medical ultrasound applications nowadays, however, the door is still open wide for more implementations of different measurements.

This study is a part of a novel method proposed to measure the volume of 3D echo images of the right ventricle.

Generally, measuring the real dimensions of an object in image requires information about the resolution of imaging system (imaging tool), the distance between the object and the acquiring tool, and the focal length. Commonly, Ultrasound's references mentioned that the ultrasound resolution depends on the ultrasound frequency, where increasing frequency gives better resolution [7].

II. PHYSICAL PRINCIPLES OF ULTRASOUND RESOLUTION

Alexander and Swanevelder defined the spatial resolution of ultrasound as the ability to differentiate between structures that are closely related [2]. This resolution depends on the wavelength (frequency) and special pulse length (SPL) where it increases directly proportional to the increasing of frequency.

The resolution of ultrasound has two sides to be considered; Axial (longitudinal) resolution and lateral resolution. Axial resolution represents the ability to differentiate between objects that lie along the central axis of the ultrasound beam, as in Fig. 1. However, the lateral resolution is defined as the ability to distinguish between objects perpendicularly with the ultrasound beam as discussed in [4,5, 7] and as illustrated in Fig. 2.

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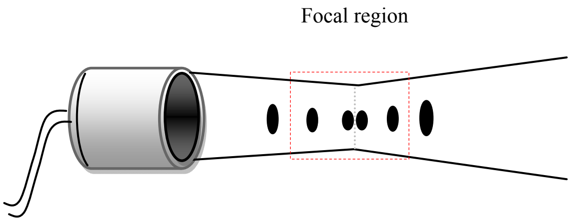

Fig. 2. Axial resolution, [5].

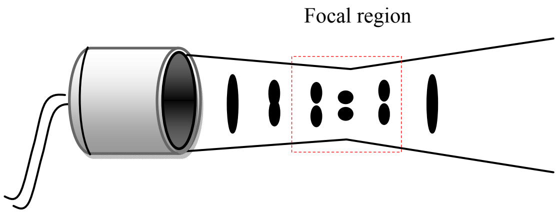

Fig. 2. Lateral resolution, [5].

Axial resolution can be affected by different parameters such as Spatial Pulse Length (SPL), Wave Cycles, Sound Frequency, and Wavelength. Axial resolution can be defined mathematically as the multiplications of the number of wave cycles (c) and the wavelength (λ).

$$SPL = \lambda_c \tag{1}$$

$$wavelength(\lambda) = {}^{c}/_{f} \tag{2}$$

where f is the sound frequency, and

$$AxialRsolution = {}^{SPL}/_{2} \tag{3}$$

In the meanwhile, the lateral resolution depends on the beam geometry as illustrated in Fig. 3. The lateral resolution can be increased by increasing of the Near Zone Length (NZL). The (NZL) can be computed from the equation:

$$NearZoonLength(NZL) = {}^{D^2}/_{4\lambda} \tag{4}$$

where D; is the beam diameter.

The focal region has the highest resolution, where at this region the axial and the lateral resolution are at maxima. This region can be produced by reducing the NZL or increasing the beam width [2]. However, the Far Field Zone is the divergent region (FFZ) of the transducer beam. The divergence angle depends on the wavelength and as it is indicated in the following equation:

$$\sin\theta = \frac{1.2\lambda}{D} \tag{5}$$

$$FocalRegionWidth = {}^{D}/_{2} \tag{6}$$

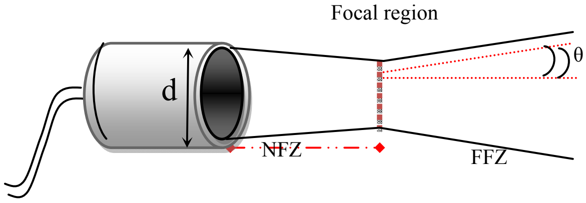

Fig. 3. Beam geometry, [5].

From the detailed observations that they are explained above, we can condense that; measuring the ultrasound resolution required information about frequency, wavelength, near zoon length, and number of cycles. In this article, 3D imaging system has been used to perform the experiment. However, the technical information of the probe is limited to:

1) FR (Hz): for the frame rate.
2) Gain: Contrast
3) Pyramid length. Determine the beam length
4) c: Cycles

However, these information do not cover all the parameters that are required to measure the resolution. Therefore, we conducted an experiment to estimate the resolution.

III. 3D ULTRASOUND IMAGES RESOLUTION ESTIMATION

The experiment used different materials and sizes such as illustrated in Fig. 4 and 5 where the experiment used frozen beef meat cubes and metal sticks with different size from 0.1 to 1 cm.

The ultrasound probe is fixed to the wall of a plastic container filled with plain water. A ruler is also fixed to the bottom of the container to measure the distance between the object and the transducer.

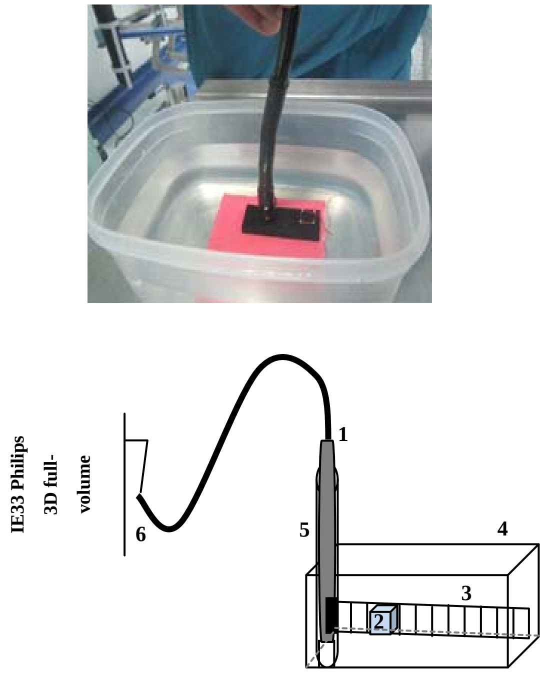

Fig. 4. Experiment tools and materials. 1- 3D–multiarray (X7-2T) transducer, 2- known dimension object, 3- ruler, 4- water container, 5- tube to fix the transducer, 6- IE33 Philips (QLAB software)

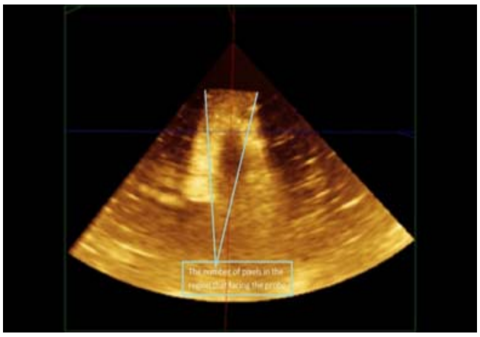

Fig. 5. 3D image of a cube of beef meat. Compute the width of the part that facing the probe.

Methodology: For each of objects, a sequence of 3D full volume acquiring is done with slightly changes of the distance at each time between the object and the probe. Changes in distance start from 1cm up to 5 cm. The purpose of changing the distance is to examine the effect of far field zone. Next step is to calculate the number of pixels at the 3D image and find the ratio, in cm, of the number of pixels with the real dimension of their corresponding object. The ratio is computed from the following equation:

$$scale\left(\frac{cm}{pixel}\right) = \frac{Real\ Width(cm)}{TheObject\ Width\ in\ 3D\ Image\ (pixel)} \quad (7)$$

$$mean\left(\frac{cm}{pixel}\right) = \frac{\sum_{i=1}^{n} scale_i}{n} \quad (8)$$

where, p is the number of iteration (p= 1, 2… n).

Then, normalize the resolution to (inch/pixel) units using the following equation:

$$Resolution\left(\frac{inch}{pixel}\right) = mean\left(\frac{mm}{pixel}\right) \times 0.039\left(\frac{inch}{mm}\right) \quad (9)$$

where; 1 inch=0.45 cm, and 1 cm=0.39 inch

IV. RESULTS AND DISCUSSION

Implementing of the resolution measuring method has been explained in Table I.

TABLE I
MEASURING THE RESOLUTION

Iteration (p)	Probe Distance (cm)	no. of pixels in image (pixel)	Real size of object (cm)	Resolution =inch/Pixel
1	1	94.51	1	0.010581
2	1	118.01	1	0.008474
3	1	124.1	1	0.008058
4	1	60.01	1	0.016664
5	1	135.77	1	0.007365
6	1	131.15	1	0.007625
7	1	135.02	1	0.007406
8	1	60.8	1	0.016447
9	1	207.51	2.5	0.012048
10	1	135.01	1	0.007407
11	1	139.86	1	0.00715
12	1	107.25	2.5	0.02331
13	2	96.01	1	0.010416
14	2	142.25	1	0.00703
15	2	208.5	2.5	0.01199
16	4	78.92	1	0.012671
17	4	51.85	1	0.019286
18	4	113.64	2.5	0.021999
Total				0.215927
Mean				0.011996
Resolution				0.00467844

The predicated resolution of this experiment has been used to compute the right ventricle end-diastolic volume (EDV) for 12 patients. Principles of disk summation method have been used by [1], as in Fig. 6. By slicing the RV into 16 longitudinal slices, the volume will then be compute by the following equations:

$$Segmented\ Area = \sum_{i=1}^{n}\sum_{j=1}^{m} S(i,j) \times Resolution \quad (10)$$

where s(i,j) is the segmented region components.

$$Disk\ Width = Slice\ Thickness \times Disk\ Width \quad (11)$$

$$RV_{volume} = \sum_{slc=1}^{16} (Segmented\ Region \times Disk\ Width) \qquad (12)$$

Where n is the number of disks. The EDV measurement results are listed in table II.

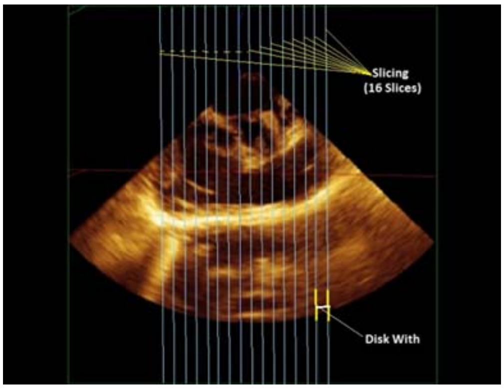

Fig. 6.Disk summation method

TABLE II
RIGHT VENTRICLE END-DISTALLY VOLUME

P.no.	End-Distally volume
1	126.9
2	126.5
3	100.8
4	110.9
5	105.1
6	100
7	118.9
8	117.3
9	110.9.3
10	152.1
11	96.7
12	81.8.2

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