A Prototype for 3D Ultrasound Scanning and Reconstruction

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***Abstract-* We introduce a new 3D Ultrasound system that can upgrade any conventional 2D Ultrasound system to 3D one. Our new 3D Ultrasound system acquires the 2D images and reconstructs the 3D volume using many techniques. We described each of the scanning and reconstruction modes that vary in quality, applicability for anatomical organs and cost. We designed and manufactured a mechanical movers of very low price and applicable to every organ for 3D ultrasound scanning. Finally, our 3D ultrasound system is of very low-cost and Pc-Based solution that upgrades any 2D system to 3D one.**

***Keywords*- 3D Ultrasound, Mechanical, Electromagnetic, Positioning System, Scanning and Acquisition.**

I. INTRODUCTION

Over the past few years ultrasound imaging has made tremendous progress in obtaining important diagnostic information from patients in a rapid, noninvasive manner and has benefited from significant improvements in image quality and visualization clarity. Advances in technology, particularly high speed computing and storage hardware; have further expanded the possibilities for maximizing patient diagnostic information [1].

2D ultrasound traditionally has relied on acquisition of images from a variety of orientations in which the operator has a good eye-hand linkage to assist in feature. As a result, ultrasound imaging has been one of the few areas of medical imaging that has not routinely used standardized viewing orientation, a relying instead on the interactivity of the process to optimize visualization f patient anatomy. Because viewing of important landmarks is essential for interpretation and identification of anatomy, particularly in less skilled practitioners, one benefit that 3D ultrasound brings to patient diagnosis is the data review may be carried out at the console after the patient has left the clinic because patient data can be reoriented to standard anatomic position, viewer comprehension and recognition of anatomy are enhanced [1].

An important part of 3D ultrasound is the ability to review patient data interactively. The flexibility to rotate, scale, and view objects from perspectives that optimize visualization of the anatomy of interest is critical. Physician involvement in optimizing and enhancing the tools to accomplish this essential in the ongoing evaluation of all these techniques [2].

At present, real-time 2D ultrasound makes it possible for physicians to make important contributions to patient management. However, there are occasions when it is difficult to develop a three-dimensional impression of the patient anatomy, particularly with curved structures, when there is a subtle lesion in an organ, when a mass distorts the normal anatomy, or when there are tortuous vessels or structures not commonly seen that can be difficult to visualize with 2D ultrasound methods. The typical approach to overcome this problem is to scan repeatedly through the region of interest to clarify the exact spatial relationships. Complex cases often make it difficult even for specialists to understand three-dimensional anatomy difficult to demonstrate with 2D ultrasound because of the particular planes that must be imaged to develop the entire three-dimensional impression [2].

Advanced technology permits volume-imaging methods to be applied to diagnostic ultrasound incorporating interactive manipulation of volume data using rendering, rotation, and zooming in on localized features. Integration of views obtained over a region of a patient with 3D ultrasound may permit better visualization in these situations and allow a more accurate diagnosis. Although the eventual role for 3D ultrasound has yet to e determined, there is little doubt that its impact will be broad and substantial. 3D ultrasound also has an important role in demonstrating normalcy and reassuring patients. Ultimately, the success of 3D ultrasound methods will depend on providing performance and capabilities that exceed those of 2D sonography. In the near future 3D ultrasound will be a routine part of patient diagnosis and management [3].

In this paper we introduce a low cost 3D Ultrasound upgrade system that can work with any conventional 2D Ultrasound system based on either mechanical or electromagnetic positioners and we will stress on the scanning modes and reconstruction methods.

II. VOLUME ACQUISITION METHODS

Our system contains a video capture card which is connected to the video-out port of the 2D ultrasound system, the 3D system capture the 2D images from the 2D system as fast as possible up to 30 frames/second, to reconstruct the 3D volume from the acquired images we must know the position of 2D images relative to each other in the space. We do this using 3 techniques

1. Electromagnetic Position Sensor
2. Mechanical Mover
3. Untracked Movement

Electromagnetic position sensor is composed of a transmitter and a receiver and both are connected to our system, we can read from the sensor the 6 degrees of freedom of the sensor relative to the transmitter, the sensor is fixed on the ultrasound transducer. During the acquisition of images we also capture the 6 degrees of freedom of each image (Fig. 1).

Figure 1: The electromagnetic sensor is attached to the transducer.

The solution of the position sensor gives very accurate results but it's too costly (4000$) (Fig. 2).

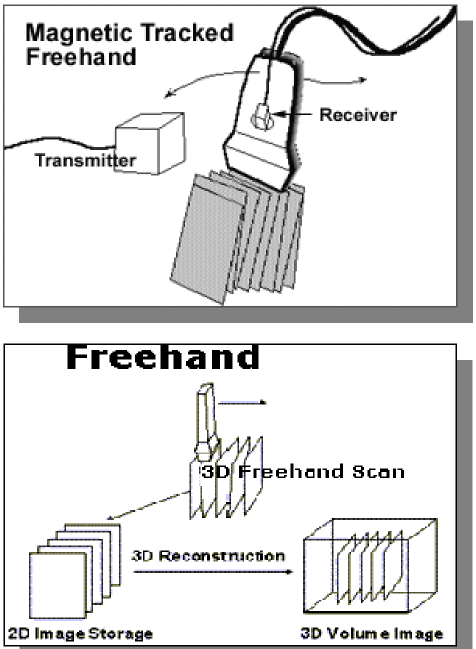

Figure 2: Freehand movement of transducer showing irregular separated images.

After the acquisition process we insert images inside an empty cube according to their orientations then gaps between images inside the volume are filled using nearest neighbor interpolation.

The second technique is the mechanical mover; the mechanical mover is a device that moves the transducer in a known fixed movement. The mechanical movement is synchronized with grabbing images. The movements can be Linear, Fan, or Rotational movement.

Linear movement

The aim of this movement is to acquire 2D images in parallel way image after image like the pages of a book, then the images are stacked one over another to construct the 3D volume (Fig. 3).

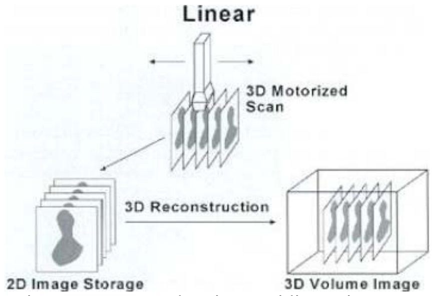

Figure 3: Linear movement showing equidistant images separation.

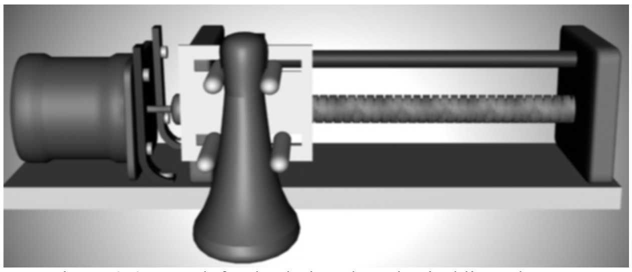

Figure 4: 3D graph for the designed mechanical linear locator.

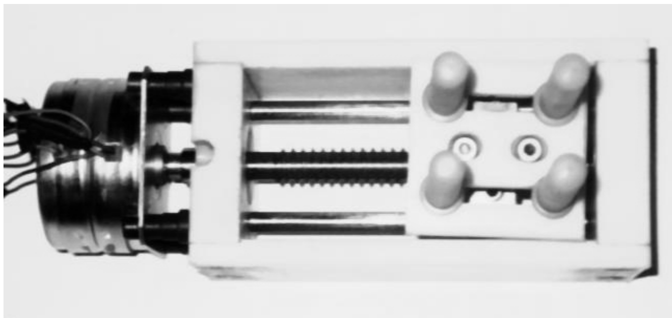

Figure 5: Actual image for the designed linear locator.

As we see in figure the system is very simple and consist of:

Motor: Stepper motor its specifications are 7.5 degrees 24 V dc, 18.8 Ω winding resistance (Fig. 5).

Screw: We use screw to move the transducer attachment, the attachment is coupled or fixed with a nut and the nut is located in a nut house. This screw is made of steel.

Nut: The nut is coupled with the screw, when the screw rotates the nut move according to direction of rotation. The nut is made of copper.

Guides: The system have two guides above and under the screw make the movement of screw and attachment stable and prevent vibrations because vibrations will distort the acquired images.

Base: Used to fix the whole system and made of PVC.

Two supporting plates: Carrying the screw, guides and bearings and made also of PVC.

Bearing: Act as house to the ends of screw and guides.

Attachment: The function of the attachment is to catch the transducer. It is made of PVC and consist of palette with two sliced and elongated gaps or threads, four legs slide on the palette to fix the transducer and match many types of probes (Fig. 4).

Tilt movement

Actually this movement in design and achieving was difficult some kind. Because we want to move the transducer as its end like a center of a circle as in figure 6. We acquire image after image like a part of a sector in a circuit.

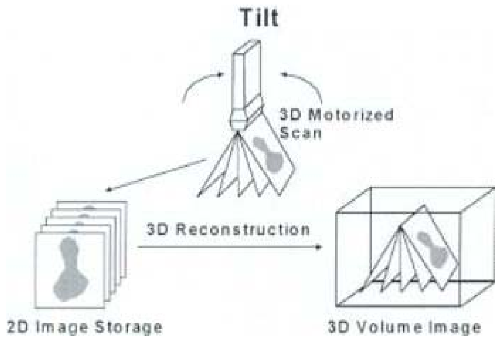

Figure 6: Tilt movement showing equiangular images separation.

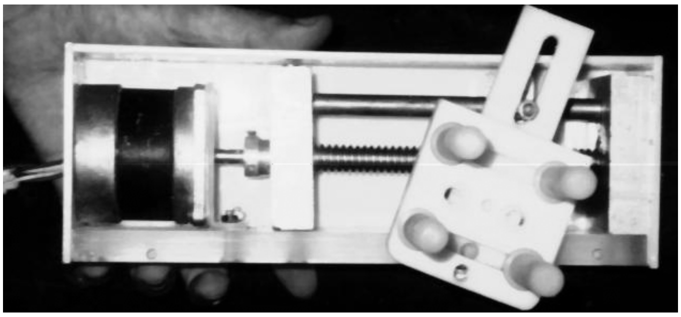

Figure 7: Actual image for the designed mechanical tilting locator.

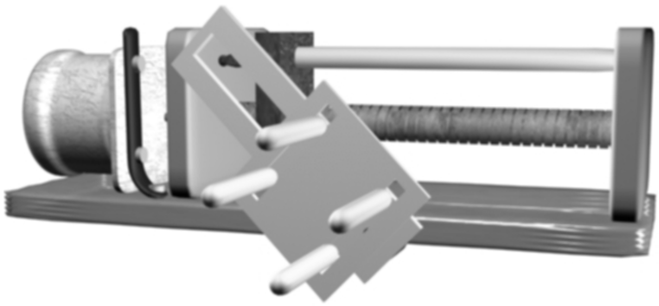

Figure 8: 3D graph for the designed mechanical tilting locator.

There were many techniques to achieve this movement. We chose a simple way similar to the linear system to do this (Fig. 7).

As we see in figure the system is very simple and consist of:

Motor: Stepper motor its specifications are 1.8 degrees, 24 V dc, 18.8 Ω winding resistance.

This means that it needs 200 steps to get one cycle.

Screw: We use screw o move the transducer attachment, the attachment is coupled or fixed with a nut and the nut is located in a nut house. This screw is made of steel. It is 12.2cm its pitch is 2 mm, this means every complete cycle from the screw get 2mm distance.

Nut: The nut is coupled with the screw, when the screw rotates the nut move according to direction of rotation. The nut is made of copper.

Guides: The system have one guide above the screw make the movement of screw and attachment stable and prevent vibrations because vibrations will distort the acquired images.

Base: Used to fix the whole system and made of plastic.

Two supporting plates: Carrying the screw, guides and bearings and made also of aluminum.

Bearing: Act as house to the ends of screw and guide.

Attachment: The function of the attachment is to catch the transducer. It is made of PVC and consist of a palette with two sliced and elongated gaps or threads, four legs slide on the palette to fix the transducer and match many types of probes. The palette is coupled with a driver; the driver is a piece of PVC coupled with nut house with nail (Fig.8).

When the screw turn, the nut house move horizontally from left to right and vice versa, the driver is fixed to a bearing which is fixed in the base of the system and have a thread that the nail move inside it. Thus the net action like mentioned above as a sector of a circle.

Rotational movement

This movement is simple in use, as we see in figure 9 the system consists of:

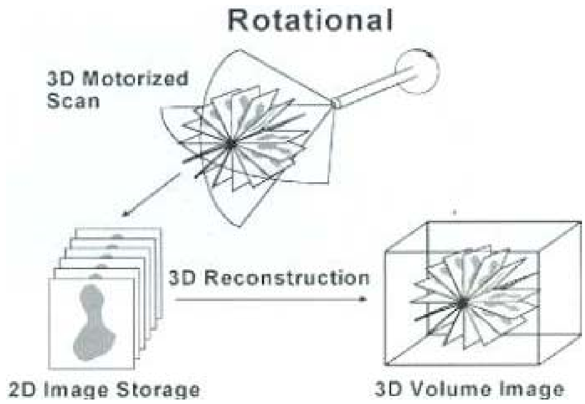

Figure 9: Rotational movement showing equiangular images separation.

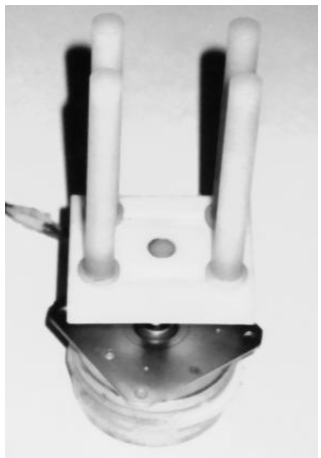

Figure 10: Actual image for the designed mechanical rotational locator.

Attachment: The function of the attachment is to catch the transducer. It is made of PVC and consist of a palette with two sliced and elongated gaps or threads, four legs slide on the palette to fix the transducer and match many types of probes. The palette is coupled with a driver; the driver is a piece of PVC coupled with nut house with nail (Fig. 10).

When the screw turn, the nut house move horizontally from left to right and vice versa, the driver is fixed to a bearing which is fixed in the base of the system and have a thread that the nail move inside it. Thus the net action like mentioned above as a sector of a circle. We acquire the images in a circular way as figure 9.

III. VOLUME RECONSTRUCTION

After images acquisition, it's now the time of reconstruction of the volume. To do this we allocates an empty cube then we insert the acquired images inside this cube according to their positions.

Linear Volume Reconstruction:

To create a linear volume, we have to arrange the acquired images beside each other; as arranging a deck of cards over each other.

As depicted in the Figure 11 shows the 3 dimensional view (depth z, width x, height y). Since there is no gaps in between the acquired images, no interpolation is needed.

So all what we need is to multiply the depth, width and height into each other to generate the required volume.

Volume= Height x Width x Depth

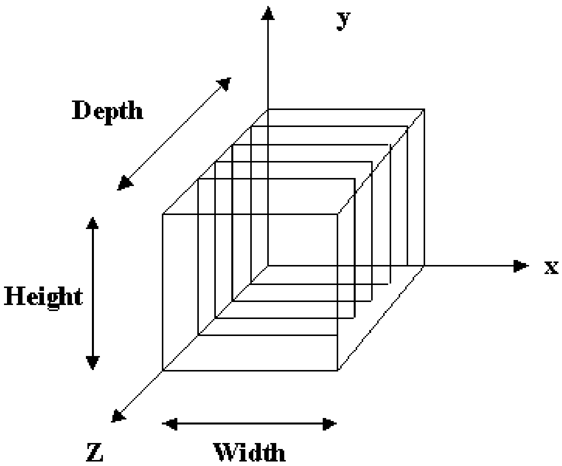

Figure 11: Linear volume creation

Tilt (Fan) Volume Reconstruction:

In the Fan volume case, we will start locating the images from 45 *degrees* to 135 *degrees* (i.e., we left 45 *degrees* the beginning and another 45 *degrees* at the end) so that the created volume would look as a fan like shape.

To compute the tilting step, we have to divide the starting angle which is 45 *degrees* by number of images, then the tilting angle will be added progressively to the starting angle until reaching the largest possible angle which is less or equal to 135 *degrees.*

Figure 12 bellow shows the creation of this technique, where the Height equals one half the width, and the width equals the depth.

Volume=(dZ)*W*H+ dY*W+W

Where

dZ=d*cos(CurrentAngle*PI/180.0)

dY=d*sin(CurrentAngle*PI/180.0)

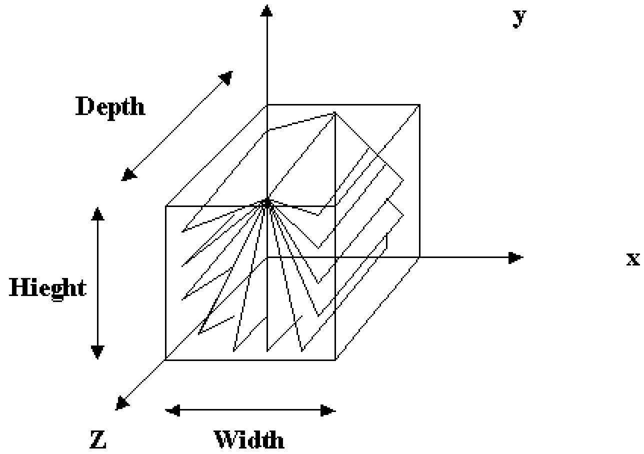

Figure 12: Tilt (Fan) Volume Creation

Rotational Volume Reconstruction:

This technique of rotational volume creation is similar to the tilt one, the main two differences is: (i**)** That we work this time on a 180 *degree* instead of 90 *degree*. (ii) We worked on the X, Y-axis this time instead of the Y, Z-axis as in the previous technique (tilting) (Fig. 13).

Volume= (dZ)*W*H+h*W+(dX)

Where

dX=d*cos(CurrentAngle* PI/180)

dZ=d*sin(CurrentAngle*PI/180)

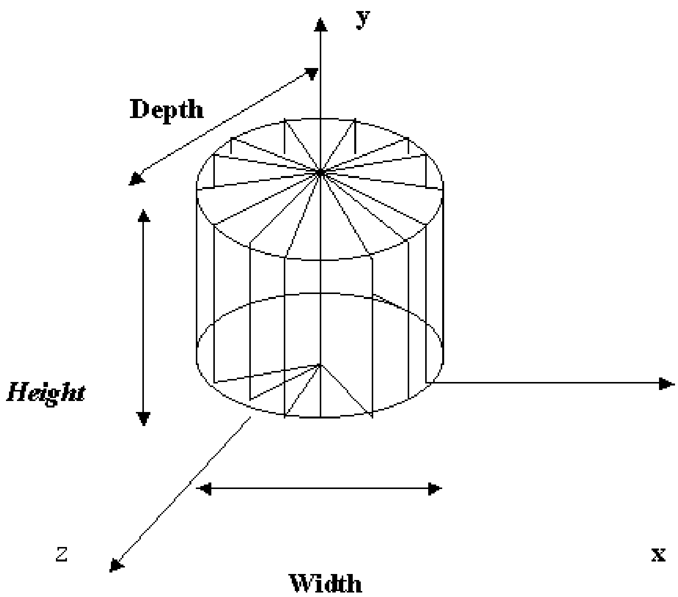

Figure 13: Rotational Volume Creation

After inserting images in the cube there are gaps between images inside the cube, which doesn't contains any data to fill these gaps we apply a nearest neighborhood interpolation on all gaps inside the volume.

IV. CONCLUSION

3D Ultrasound is one of the most new techniques in ultrasound imaging which proved its powerfulness in diagnosis and visualization of many organs, which were impossible using conventional 2D Ultrasound. The 3D capability is found only in the high-end ultrasound systems that are very costly. This cost prevents many sonographers from purchasing 3D Ultrasound systems.

Real-time 3DUS systems using 2D arrays are still unavailable for routine imaging, which means that most of the approaches have focused on using convenient one-dimensional (1D) transducer arrays. In this scanning approach, a series of 2DUS images is recorded rapidly while the conventional transducer is manipulated over the anatomy using a variety of techniques. These digitally recorded 2DUS images are then reconstructed into a 3DUS data and made available for viewing .To avoid geometric distortions and inaccuracies, the relative position and angulation of each 2D image must be known accurately. One way to accomplish this is to use mechanical means to move the conventional transducer over the anatomy in a precise, predefined manner. As the transducer is moved, the 2DUS images generated by the ultrasound machine are acquired at predefined positional intervals (either angle or distance).

In the early days of development, images were stored on videotape for later processing, but with advances in computer technology and ultrasound instrumentation, they are now more commonly digitized into an external computer immediately or stored in original digital format in the ultrasound system's computer. Either the ultrasound machine's computer or the external computer reconstructs the 3DUS data using the predefined geometric information, which relates the digitized 2DUS images to each other. To ensure that the scanning procedures avoids missing any regions in the body, the spacing interval between the digitized 2DUS images is pre-computed and usually is made adjustable to minimize the scanning time while optimally sampling the volume.

Various kinds of mechanical scanning systems have been developed, requiring the conventional transducer to be mounted in a special assembly and rotated or translated by a motor. Table 1 compares the built-in 3D ultrasound module (complete 2D and 3D system) vs. 3D ultrasound solution (upgrade).

TABLE 1: BUILT-IN VS. EXTERNAL FIXTURE IN 3D ULTRASOUND IMAGING SYSTEMS.

Scanning approach	Advantages	Disadvantages
Integrated 3D Probe	- Small size - Interface for ultrasound machine optimized for 3D	- Requires the purchase of a special ultrasound machine - Advances in ultrasound technology not immediately
External Fixture	- Does not require special ultrasound machine - Can interface to many machines in department - Advances in ultrasound technology available immediately in 3D	- Bulkier and heavier fixture - System not optimized for 3D without special calibration

When the motor is activated under computer control, the mechanical assembly rotates or translates the ultrasound rapidly over the region being examined. Assembly have been developed that vary in size from small integrated 3D probes housing the mechanical mechanism and motor to ones employing an external fixture connected to the conventional 2DUS transducer.

In general, the integrated mechanical scanning 3D probes are small, allowing easier use by the operator, and can be optimized for 3D imaging; however, they require the purchase of a special ultrasound machine capable of interfacing to these probes. The external fixture approach results in bulkier assemblies, but they can accommodate any conventional ultrasound machines transducers, obviating the need to purchase a special-purpose 3DUS machine.

In this way, improvements in image quality and imaging techniques (e.g., power Doppler) afforded by advances in the ultrasound machine also can be achieved in 3D. In addition, because the external fixtures can house a transducer from any ultrasound machine, the 3D capability can be extended to a number of ultrasound machines in a department.

A number of investigators and commercial companies have developed different types of mechanical assemblies used to produce 3DUS data. These can be divided into three basic types of motions: linear, tilt, rotation. These clinical applications of each type are shown in Table 2. The advantages and disadvantages of each type are shown in table 3.

TABLE 2: SUMMARY AND MAJOR USES OF MECHANICAL SCANNING TYPES

Scanning types	Arrangement of images	Major uses
Linear	- Parallel to each other with equal spacing.	- Vascular (carotids and peripheral), Breast
Tilt	- Fanlike geometry with equal angular spacing.	- Obstetrics, abdominal, prostate
Rotation	- Propeller-like geometry with equal angular spacing.	- Cardiac, prostate, gynecology.

TABLE 3: ADVANTAGES AND DISADVANTAGES OF MECHANICAL SCANNERS

Scanning type	Advantages	Disadvantages
Linear	- Simple geometry easy to reconstruct in 3D. - Angulation easy to interpret for Doppler imaging.	- Bulky mechanism.
Tilt	- Relatively compact mechanism. - Simple geometry easy to reconstruct in 3D.	- Resolution degrades with depth.
Rotation	-Ideal for transrectal and transesophageal imaging. - Compact mechanism.	- Any motion of axis of rotation will generate artifacts in the center of the image.

V. ACKNOWLEDGMENT

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VI. REFERENCES

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