A TECHNIQUE FOR IMAGING THREE-DIMENSIONAL STRUCTURES AND COMPUTING THEIR VOLUMES USING NON-PARALLEL ULTRASONIC SECTOR SCANS.

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A computer-based system has been developed for the reconstruction of an object from a series of non-parallel sector scans from which volume can be obtained. Sector scans from different portions of the object are collected and outlined using a real-time sector scanner and light pen, while the three-dimensional orientation of each scan plane is determined by a spark gap position locating system. Using this information, the computer then creates an image which can be viewed in perspective or used to find volume. Thirty reconstructions were obtained on 7 water-filled balloons whose volumes ranged between 50 and 317 cc; the range of errors was -9.3 to +7.8%, correlation coefficient was .99 and standard error of the estimate was 9.7 cc. It is hoped that this system will be useful in several areas including the heart, the liver, the fetus, and the carotid artery.

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The introduction of real time sector scanners into the medical community has made it possible to view both static and dynamic structures in a way that is much more visually informative than the conventional echo method. This new ultrasound modality can be made even more useful if it is coupled to a three-dimensional position sensing device and a computer, which then makes it possible to extend the two-dimensional information obtainable with the sector scanner into three dimensions. This report summarizes a hardware-software system for three-dimensional reconstruction of an organ as a series of ultrasonic sector scans which can be viewed as a three-dimensional image or used to find volume. Results obtained with trials on seven balloon models in a water tank are also described.

The basic hardware components of this system are a real time sector scanner, a spark gap position locating system, a video graphic computer terminal and a computer. The scanner used in the balloon trials is part of a 5 MHz Duplex system developed for the simultaneous display of anatomic information with the scanner and flow information with a range-gated pulsed Doppler.[1] The position locating system is a microprocessor-based device which finds three-dimensional coordinates of a small spark gap by determining the transit times to three orthogonal microphones of an acoustical shock wave produced by the spark gap. Three such gaps are mounted on the scan head in order to allow the position and orientation of each scan plane to be determined.[2] The video graphics terminal utilizes a mixer to combine a video image of the real time sector display (as produced by a TV camera) with computer generated

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output obtained from a Tektronix 4012 terminal and a Princeton Electronics Products 402 scan converter. A light pen is used in digitizing the various outlines, and communication with the computer is achieved via a 1200 baud phone line.

The software is written in Fortran and occupies 39K 36-bit words of a Digital Equipment Corporation PDP-10 computer (including the Fortran run-time system). The main program, SCANR2, is an executive which accepts keyboard commands for carrying out the different phases of data collection and storage, three-dimensional graphics and volume determination. The commands in turn call subroutines which were either written specifically for this project, are part of a general purpose 3D plotting library that we have developed (PLOT3D) or are part of the Tektronix Terminal Control System, the routines of which are used to control the actual beam movement on the CRT.[3]

In order to obtain a reconstruction the operator first defines a "patient" coordinate system by placing the scan head at 3 points (corners of the water tank) and firing the spark gaps. He then proceeds to collect a series of scans, the goal being to image as much of the object as possible. For each scan the sparks are fired and position information is sent to the computer while the scan is recorded on video tape. At a later time the scans are recalled from the tape recorder, digitized with the light pen, and combined with the appropriate position information in order to determine the three-dimensional relationship of each scan to the patient coordinate system. The resulting reconstruction may then be viewed from any given perspective by means of the keyboard commands.

If volume is desired the operator must use the light pen to indicate the endpoints of the object at the time the outlines are being digitized (Fig 1:A,B). These points are used by the computer to determine a long axis and from that, an "organ" coordinate system in which the long axis becomes the Z-axis. Figure 1A shows 17 reconstructed scans from one balloon displayed in terms of this organ system. (In general between 11 and 17 scans were collected for the balloons studied.) The computer next rotates a plane about the long axis in 12 increments of 15 degrees each, and determines at each increment the intersection points between the plane and each input scan. These points are then sorted into a set of interpolated scans. Finally, the interpolated scans are sliced by 21 planes perpendicular to the long axis, and volume is determined by Simpson's Rule from the individual cross sectional areas of the slices. Figure 1B shows the resulting model obtained from the original scans.

The system has been tested on 7 water-filled balloons whose volumes (by direct measurement) ranged from 50 to 317 cc. Several

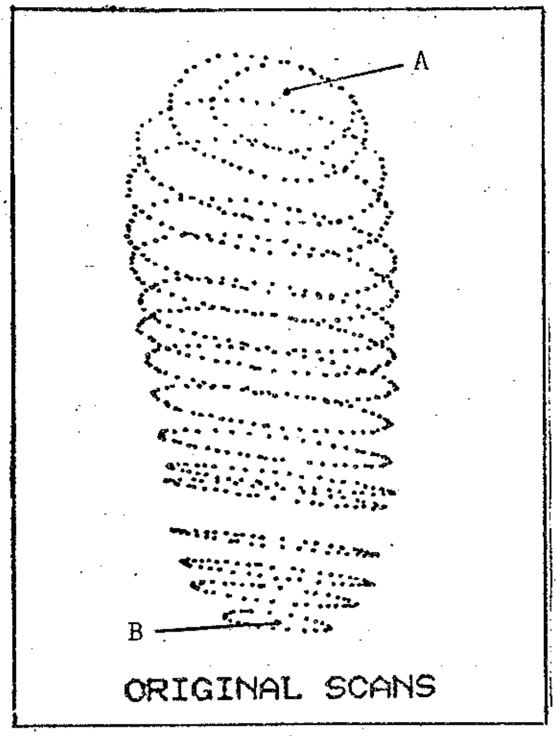

Figure 1A: 17 scans of a water-filled balloon shown with long axis in vertical direction.

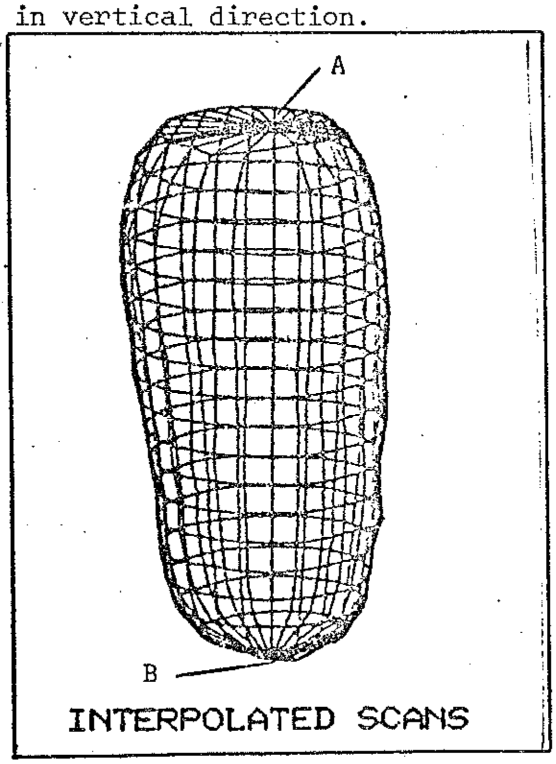

Figure 1B: Computer-interpolated scans used in finding volume.

reconstructions were done on each balloon for a total of 30 volume determinations. The range of errors was -9.3 to +7.8%, the correlation coefficient .99, standard error of the estimate 9.7 cc.

The original motivation for this system was the desire to find a better means of determining left-ventricular volume than the current one-dimensional echo technique which has been shown to be inaccurate in many instances.[4] It was felt that a series of scans from all portions of the ventricle should be more accurate than a single measurement because more information is being obtained. Because of the small cardiac windows available for examining the heart it was thus necessary to allow non-parallel scans to be collected. However, once the program was designed in this manner, it became clear that it may have application in many areas since it is often very difficult to maintain good ultrasonic image quality throughout the length of an organ if scans are required to parallel. Thus it is hoped that in addition to providing information about heart volume this program will be useful for carotid artery imaging[5], fetal volume, liver volume, and possibly other volumes as well.

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