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Development of an ultrasonic system for three-dimensional reconstruction of the fetus

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1 Introduction

In recent years, diagnostic imaging using ultrasonic tomography has been commonly used in the field of obstetrics. But the ultrasonic diagnostic devices available at present can capture only one section of the fetus. We have developed a system for ultrasonic three-dimensional reconstructions of the fetus in order to facilitate the understanding of the three-dimensional structure of the fetus and also to make three-dimensional recording possible. Here we describe this system.

2 Principle

The procedure for 3-D reconstruction of the fetus from ultrasonic tomographic images is illustred in figure 1. Successive parallel ultrasonic tomographic images are entered into a computer together with positional information. The computer extracts the part of the fetus from each tomographic image and builds up these images three-dimensionally according to the positional information.

The principle of three-dimensional (3-D) display is illustrated in figure 2. The direction of a viewing point relative to the three-dimensionally reconstructed fetal image is designated. The plane of projection vertical to this direction is assumed. The brightness of each element of the picture on the plane of projection is determined proportionally to the distance between the picture element and the fetal image. In other words, the shorter the distance, the brighter the pictorial element, and the longer, the darker that element. It is possible to visibly appreciate the fetus three-dimensionally by regenerating this projection plane on the monitor TV [1].

Curriculum vitae

KAZUNORI BABA *M.D., was born in 1952. He received the B.E. degree from the University of Electro-Communications (Japan) in 1975. he then entered medical school at Osaka University (Japan) and graduated as an M.D. in 1979. He has worked in the Department of Obstetrics and Gynecology, University of Tokyo (Japan), and received M.D. of Science from the university in 1987. At present he is working in the field of perinatal medicine at Saitama Medical Center in Japan.*

3 System and methods

3.1 Configuration

The configuration of the system that we have developed is shown in figure 3. The data from the position-sensor attached to an ultrasonic probe are entered into a microcomputer, where they are converted into a form that can be recorded on a video tape as an image. This new image is simultaneously superimposed on the ultrasonic tomographic image and recorded on the video tape [2].

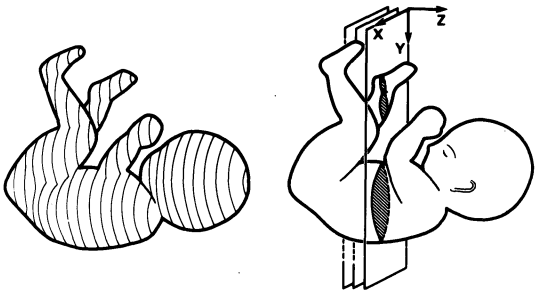

Figure 1. Procedure for 3-D reconstruction of the fetus from ultrasonic tomographic images.

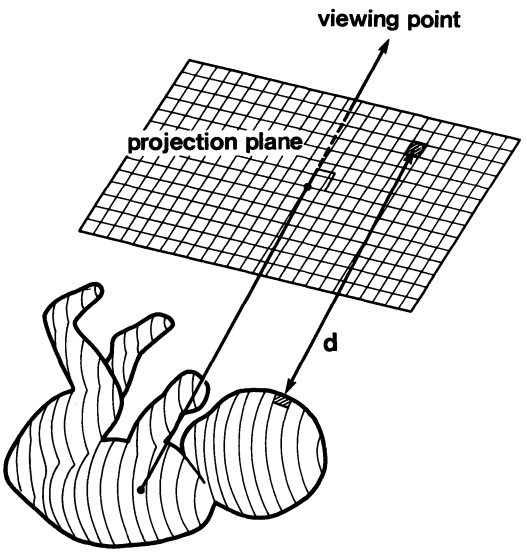

Figure 2. Principle of 3-D display.

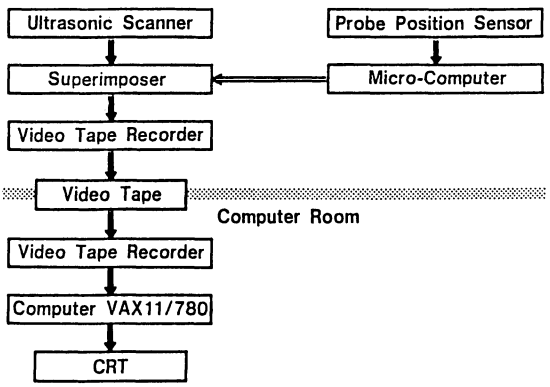

Figure 3. Configuration of our system.

Thereafter, these new data on the video tape are entered into the minicomputer. This minicomputer produces three dimensional reconstructions, and using computer-graphics displays the images which were generated on television monitor.

Separation of data acquisition from data entry was done in order to make the examination time for patients as short as possible, so that discomfort to the patients was reduced and the effect of fetal movement was minimised.

3.2 Position sensor

Either a real-time linear array probe of an ultrasonic scanner SONOVISTA-PX (Mochida Co., Ltd.) or a convex array probe of an ultrasonic scanner SSD-280 (Aloka Co., Ltd.) was mounted on the position-sensing arm of a manual compound scanner MSU-10c (Aloka Co., Ltd.) in order to detect the position of the probe (figure 4). The position detecting components are mounted on the bench in such a way as to have 5 degrees of freedom of movement as shown in figure 4 to enable the plane to be measured to be set easily.

3.3 Recording system

A microcomputer CZ-802C (Sharp Co., Ltd.) is used to convert the positional information to the recording of an image on a video tape. This image is superimposed onto the ultrasonic tomographic picture simultaneously using a superimposer CZ-8DT (Sharp Co., Ltd.) and recorded on the video tape. The ultrasonic tomographic image with its positional information is shown in figure 5. Each length of 3 lines on the right side represents the position (vertical and horizontal) and orientation of the probe when the tomographic image was recorded.

The speed of collection of the positional data and rewriting to the vedeo RAM in the microcomputer is so fast that the positional display can fellow rapid motion of the probe without any resulting flicker.

3.4 3-D Reconstruction and display

A minicomputer VAX11/780 (DEC) system was used for both the 3-D reconstruction and 3-D display. A repeating video tape through column feeding in the computer room, necessary images

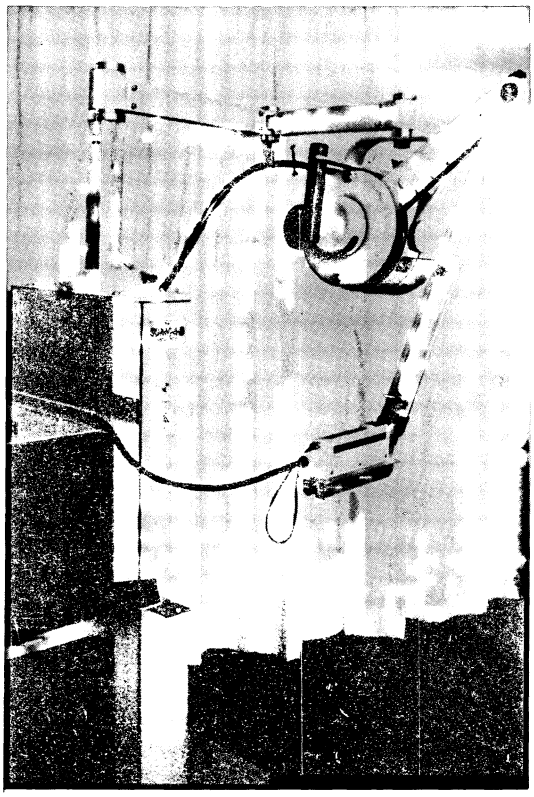

Figure 4. A real-time linear array probe mounted on a position sensing arm of manual compound scanner.

were input to this minicomputer on the basis of positional information of the probe displayed on the monitor TV. The image of the anterior uterine wall was excluded to define that of the fetus more clearly. Simultaneously, the data were compressed in the format of 128 by 128 picture elements which were then piled up in the memory of the minicomputer as 3-D data. The threshold level of brightness was designated in such a way that the fetus could be separated from the amniotic fluid. Thereafter, the 3-D images are displayed on a monitor TV using computer-graphics.

4 Results

Figure 6 shows the image generated by our system of a normal fetus of 19 weeks gestation in utero and is the composite image reconstructed three-dimensionally from 48 segments of ultrasonic tomographic images taken at 2 mm intervals. This image shows the true shape of this 19 week gestation fetus in a flexed posture.

Figure 5. Ultrasonic tomographic image with its positional information superimposed.

The probe was gently placed on the abdomen of the pregnant woman who was lying in a supine position and was then moved horizontally from the crown to the rump of the fetus to collect the data. The transverse images thus obtained were recorded on video tape. Since it takes only a few seconds for this data collection by ultrasonic inspection there is no effect of fetal movement.

Approximately 12 minutes are then required for further processing, that is, 10 minutes for the data input and 2 minutes for the 3-D reconstruction and display.

Figure 7 shows the three-dimensional image of twins at a gestation of 15 weeks, reconstructed from 54 pieces of ultrasonic tomographic images taken at 2 mm intervals.

5 Discussion

Comparison of the computer-generated image (figure 6) with a photograph of a fetus aborted at 18 weeks, (figure 8) provides us with good evidence of the usefulness and fidelity of our new system for visibly demonstrating the fetus in utero. A large head, an arm, a constricted wrist, a gripped hand, legs, heels and toes are easily identifiable. However, noise was a bar to the reproduction of an image with a surface as smooth as that of the actual fetus. Using the conventional tomographic image (figure 9) it is not easy to distinguish a twin from a singleton pregnancy unless an understand-

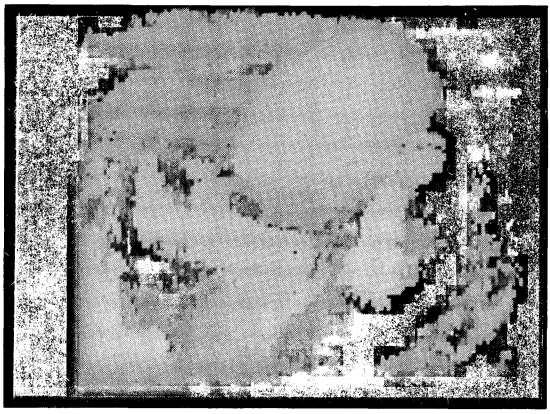

Figure 6. Computer-generated image of a normal fetus of 19 weeks gestation in utero.

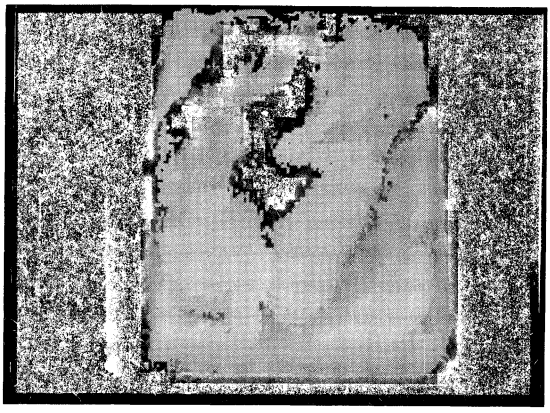

Figure 7. Computer-generated image of twins at 15 weeks gestation.

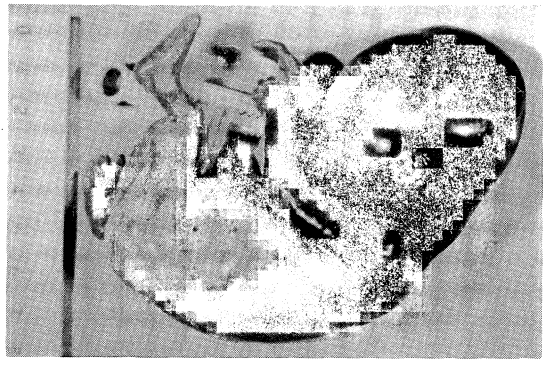

Figure 8. An aborted fetus at a gestational age of 18 weeks.

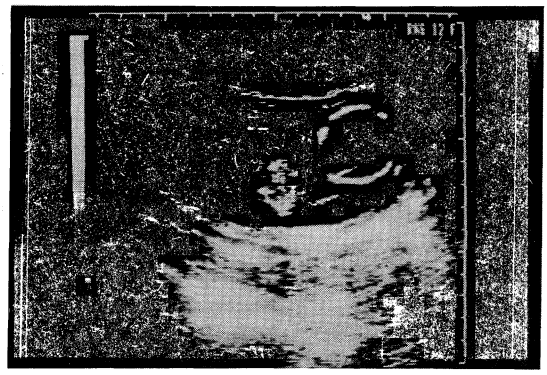

Figure 9. An ultrasonic tomographic image of twins at a gestational age of 15 weeks.

able explanation is given. Even if it is identified as a twin, it is not clear how the two fetuses are disposed. However, as shown in figure 7, the 3-D reconstructed image obtained with our system visibly demonstrates twins and shows that one is in the breech position while the other is a vertex presentation.

Amniography and feto-scopy may provide us with a more comprehensible shape of the fetus than the ultrasonic 3-D reconstructed image given by our system. However, these are invasive techniques and they cannot safely be repeatedly performed. On the other hand, ultrasonic 3-D reconstructed imaging is a non-invasive technique and can be performed repeatedly. Moreover by changing the position and direction of the viewing point, it allows easy appreciation of a solid object.

Use of this system is limited to cases in which the fetus is sufficiently separated from the anterior wall of the uterus. But if confined to a part of the body such as the face or hands, it is applicable even to the fetus at term.

The processing time of our computer system is too long for routine clinical application. But development of computer systems for industrial applications which use high speed 3-D displays, such as CAD (Computer Aided Design) are rapidly being developed present and if these are applicable, the clinical use of our system in a real-time mode is highly likely in future when it can be connected directly with the ultrasonic diagnosis device.

Future applications of this system to the screening for fetal anomalies and abnormalities of fetal growth are highly likely to be developed.

Summary

The ultrasonic diagnostic devices available at present can only represent one section of the fetus. We have developed a system for three-dimensional reconstruction of the ultrasonic fetal image in order to facilitate the understanding of the 3-D structure of the fetus and also to make 3-D recordings of this image.
Eitehr a real-time linear array probe or a convex array probe of the ultrasonic scanner was mounted on a position sensing arm of a manual compound scanner in order to detect the position of the probe.
A microcomputer was used to convert the positional information to a recording of a visual image of videotape. This image was superimposed onto the ultrasonic tomographic image simultaneously using a superimposer and was recorded on the video tape, thereafter, being recalled by the image processing minicomputer.
The minicomputer VAX11/780 (DEC) system was used for 3-D reconstruction and 3-D display. In the memory system the image of the anterior uterine wall was identified and subsequently excluded in order to visualise the fetus more clearly. The threshold of brightness was set to a high level so that the fetus could be separated from the amniotic fluid. The fetus was displayed three-dimensionally using computer graphics.
Using this system, we have made it possible to obsereve the whole image of the fetus in utero non-invasively. This system offers a method for easier understanding of the 3-D structure of the fetus in utero and also makes 3-D recording possible.
In the future, we confidently expect that this system will be used for screening for fetal anomalies and abnormalities of fetal growth.

Keywords: Computer, fetus, image processing, three-dimension, ultrasonography.

Zusammenfassung

Entwicklung eines Systems zur sonografischen dreidimensionalen Darstellung des Feten
Mit der bisherigen ultrasonographischen Diagnostik läßt sich lediglich eine Schnittebene des Feten darstellen. Wir entwickelten ein System zur dreidimensionalen Rekonstruktion des Feten, um die räumlichen fetalen Strukturen und deren Aufzeichnungen zu erhalten.
Auf den Gelenkarm eines manuellen Compoundscanners wurden entweder eine Real-time-Sonde oder eine konvex angeordnete Sonde montiert, um die Position der Sonden zu bestimmen.
Diese Informationen wurden über einen Mikrocomputer so umgewandelt, daß eine bildliche Darstellung auf Videobändern möglich wurde. Dieses Bild wurde mit dem ultrasonographisch-tomographischen Bild überlagert und nach Zurückrufen durch den den Image-Processing-Minicomputer auf Cideo aufgenommen.
Zur dreidimensionalen Rekonstruktion und Darstellung wurde ein Minicomputer-System (VAXII/780; DEC) benutzt. Im Memory-System wurde das Bild der Uterusvorderwand eliminiert, um direkt das Bild des Feten zu erhalten. Der Schwellenwert für die Wiedergabedeutlichkeit lag dort, wo der Fet von der Amnionflüssigkeit zu unterscheiden war. Der Fet wurde über eine Computergraphik dreidimensional dargestellt.
Dieses System ermöglicht, ohne invasives Eingreifen ein ganzes Bild vom Feten in utero zu erhalten. Es liefert einen leicht zugänglichen Weg zum Verständnis der dreidimensionalen fetalen Strukturen und macht eine dreidimensionale Darstellung möglich.
Die zukünftige Anwendung dieses Systems ist vielversprechend im Hinblick auf die Mißbildungsdiagnostik sowie die Feststellung eines abnormen fetalen Wachstumsverhaltens.

Schlüsselwörter: Computer, dreidimensionale Darstellung, Fet, Image-processing, Ultraschall.

Résumé

Développement d'un système pour la reconstruction échographique à trois-dimensions du fœtus
Les appareils échographiques à visée diagnostique disponibles à l'heure actuelle ne peuvent saisir qu'une coupe du fœtus.
Nous venons de développer un système pour la reconstruction échographique tri-dimensionelle afin de faciliter la compréhension de la structure tri-dimensionnelle du fœtus et aussi de rendre l'enregistrement tri-dimensionnel possible.
Une sonde linéaire en temps réel, ou sonde convexe de l'échographe a été montée sur le bras détecteur d'un lecteur manuel afin de détecter la position de la sonde.
On a utilisé un microordinateur afin de convertir l'information de position en ce qui pourrait âtre enregistré sur une bande vidéo comme une image. Cette image a été superposée sur l'image tomographique échographique simultanément par un appareil à surimpression et enregistrées sur la bande vidéo après rappel par le miniordinateur pour le traitement de l'image.

On a utilisé le système Miniordinateur VAXII/780 (DEC) pour la reconstruction et la visualisation tridimensionnelles. Sur le système de mémoire l'image du mur antérieur utérin a été séparée et éliminée pour recueillir l'image du foetus. Le niveau de seuil de la clarté

a été désigné comme le plus élevé permettant la séparation du fœtus du liquide amniotique. Le fœtus a été visualisé en trois dimensions en utilisant un graphique d'ordinateur.
Ce système nous a permis d'observer l'image entière du fœtus in utero de façon non invasive. Ce système faciliterait beaucoup la compréhension de la structure tridimensionnelle du fœtus in utero et aussi rendrait l'enregistrement tridimensionnel possible.
A l'avenir, on espère beaucoup que ce système sera très utile pour examiner les anomalies du fœtus et du développement fœtal.

Mots-clés: Echographie, fœtus, ordinateur, traitement de l'image, trois-dimensions.

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