Featured Articles

High-definition 3D Image Processing Technology for Ultrasound Diagnostic Scanners

—Realistic 3D Fetal Imaging—

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OVERVIEW: Hitachi has developed ultrasound diagnostic scanners for use in obstetrics that can provide realistic 3D fetal images by using high-quality rendering techniques capable of representing the scattering and shading of light, and skin color correction techniques that can represent "preferred colors." Realtime operation has also been achieved through the use of parallelization to perform shading plane calculations on multiple processor cores. These technologies were first introduced on three models of cart type ultrasound diagnostic scanners and the Noblus[*1] *digital ultrasound diagnostic scanner, which went on sale in April 2013. The high image quality of these scanners and the display of high-quality 3D images on portable devices help deliver new added value to clinicians who operate this equipment and to pregnant women and their families who are the ultimate beneficiaries of the technology, and enhance the product brand image of Hitachi Aloka Medical, Ltd.*

INTRODUCTION

COMPARED to other diagnostic equipment such as magnetic resonance imaging (MRI), computed tomography (CT), and X-ray machines, the particular advantages of ultrasound diagnostic scanners include that they are minimally invasive, provide realtime performance, and are able to perform scans at the bedside. These features have made them essential diagnostic tools in modern medical practice. The global market for ultrasound diagnostic scanners is approximately 580 billion yen, and is growing at an annual rate of 5.1%. Hitachi Aloka Medical, Ltd. has the leading share of the Japanese market and is working to improve its products to reach the top of the global market.

In modern medical practice, three-dimensional (3D) ultrasound imaging is used not only by clinicians to perform diagnosis, but also for other purposes such as presenting clear explanations to patients or clinicians from other specialties.

This article describes the development of high-quality rendering and skin color correction techniques for the ultrasound diagnostic scanners used in obstetrics. These image processing techniques are intended to present realistic and appealing 3D fetal images to ensure ease-of-diagnosis while also providing pregnant women and their families with reassurance and an emotional connection.

3D IMAGE PROCESSING FOR FETAL ULTRASOUND

The fact that the diagnostic work of clinicians is made easier by the ability of 3D fetal imaging to present morphological information that is difficult to identify from two-dimensional (2D) images is well known[(1)].

At the same time, pregnant women and their families like to see realistic and appealing 3D fetal images, as has been widely reported in magazines for pregnant women[(2)]. Clinicians also appreciate the benefits they provide for managing the feelings experienced by the mother, and there have been initiatives aimed at using the emotional lift that parents gain from viewing these images to also provide medical benefits[(3)].

This has created a need for the ultrasound diagnostic scanners used in obstetrics to display 3D images that have value to both clinicians and pregnant women.

*1 Noblus is a trademark of Hitachi Aloka Medical, Ltd.

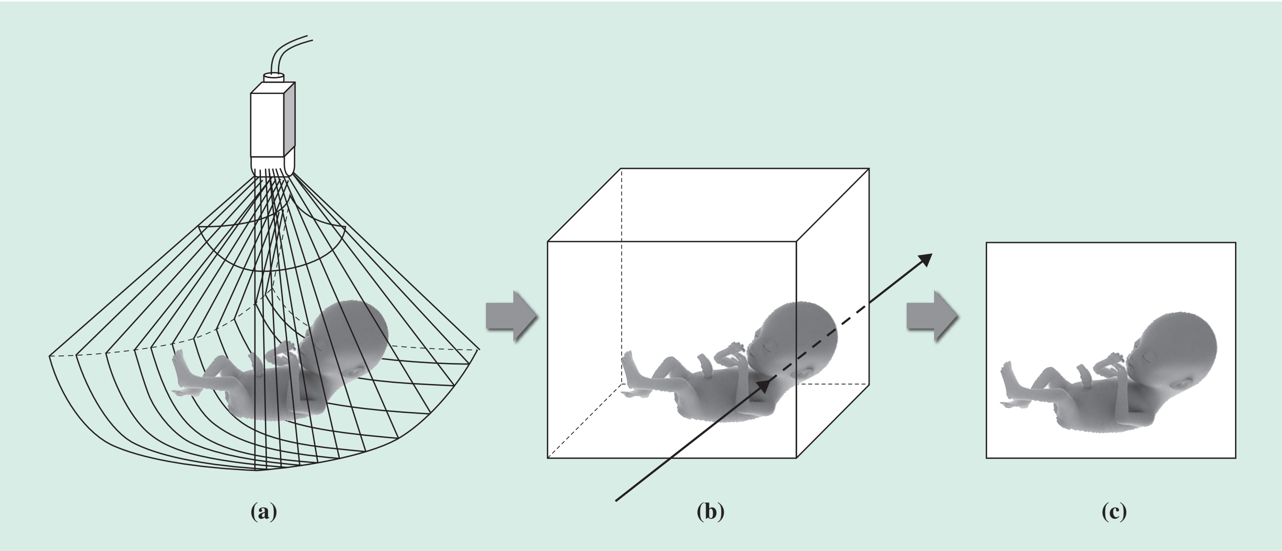

Fig. 1—Procedure for Acquiring 3D Fetal Ultrasound Images.
The probe collects 3D spatial data (a), voxelization is then performed on the collected volume data (b), and then rendering generates the two-dimensional image (c).

Fig. 1 shows the procedure for acquiring 3D fetal ultrasound images. The probe (freehand scanning or mechanically swept probe) transmits ultrasonic waves into the 3D space containing the fetus and receives the echoes to acquire ultrasonic volume data [(a) in Fig. 1]. After the voxelization of this volume data [(b) in Fig. 1], rendering is performed to generate the 3D fetal image projected onto a 2D plane [(c) in Fig. 1].

The following section describes the rendering process.

Volume Rendering

Volume rendering is a method for projecting the internal structure of a 3D object (volume data) onto a 2D surface. This explanation refers to the commonly used ray casting technique(4) (see Fig. 2). To generate a display image, ray casting identifies the volume data (voxel values) that lie on the line (ray) from the viewpoint to each projection point on the projection surface, and then calculates the pixel values for the projection points from the sum of these voxel values. Fig. 3 shows an example 3D fetal image generated using this method.

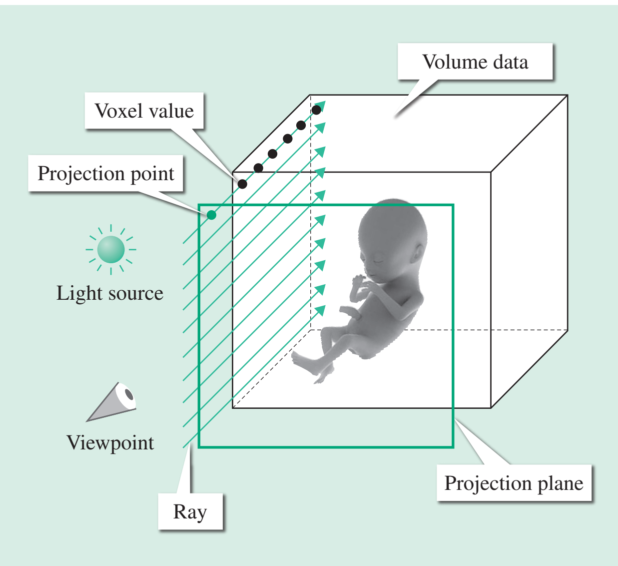

Fig. 2—Ray Casting.
Ray casting is a conventional volume rendering technique.

Fig. 3—Example of 3D Fetal Imaging Using Conventional Ray Casting Technique.
The ability to achieve a 3D effect and replicate skin coloring and texture is limited.

Although Fig. 3 shows the limited ability to create a 3D effect and express skin color and texture, these can be improved along with more accurate imaging of morphological information by faithfully recreating the behavior of natural light. As a result, this method has the potential to provide clinicians with images that facilitate diagnosis while also presenting pregnant women and their families with a favorable impression. Hitachi has now developed the realistic 3D imaging algorithm, which consists of a new rendering technique that can represent light scattering and absorption, and a correction technique that achieves appealing skin color using a method for quantifying subjective responses based on machine learning. Along with showing the fetus more realistically, these techniques produce appealing display colors.

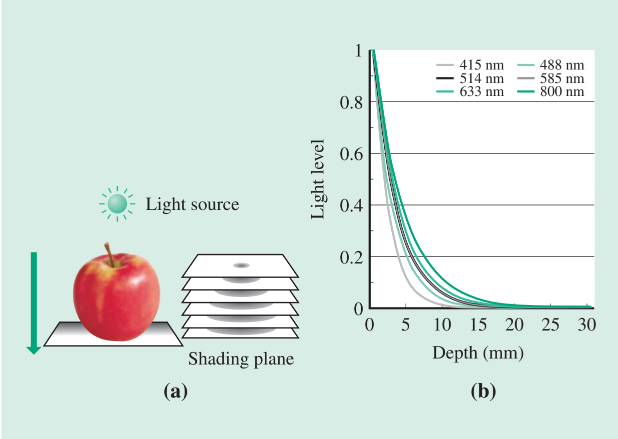

Fig. 4—Shading Plane Generation.
Figure (a) shows how the shading plane is generated and (b) shows examples of the attenuation characteristics of biological tissue at different wavelengths[6].

Realtime Processing

Since the realtime updating of volume data (3 to 4 volumes per second) is essential for displaying 3D fetal ultrasound images, rendering must be capable of processing images even faster (realtime rendering). Since rendering typically has a high computational cost, and because resources are limited on the image processing engines used in ultrasound diagnostic scanners, implementing rendering in a commercial scanner requires improvements to the algorithm through the use of techniques such as optimization and parallelization that take account of the hardware configuration. The system described here uses proprietary optimization techniques to achieve realtime rendering and display without the need for hardware modifications.

The following sections describe the principles behind the new realistic 3D imaging algorithm and techniques for improving its speed so that it can be incorporated into commercial scanners.

ALGORITHM

Replicating the color of a medium such as human skin that undergoes internal scattering generally requires the use of an extremely complex calculation called subsurface scattering[5]. If this subsurface scattering can be replicated, it can provide a realistic representation of skin.

High-quality Rendering Techniques

To represent shading when rendering is performed using the ray casting technique described above, the shading is created from the angle formed by a vector perpendicular to the light source (normal vector). When using the normal vector to create shading, however, it is difficult to replicate the shading due to indirect or transmitted light and therefore difficult to form a highly realistic 3D image. Furthermore, because the gradient calculations used to obtain the normal vector involve differentiation, this method can make images harder to read when used on noisy ultrasound images because it tends to emphasize the noise.

The proposed method uses a shading plane that takes account of the scattering and absorption of

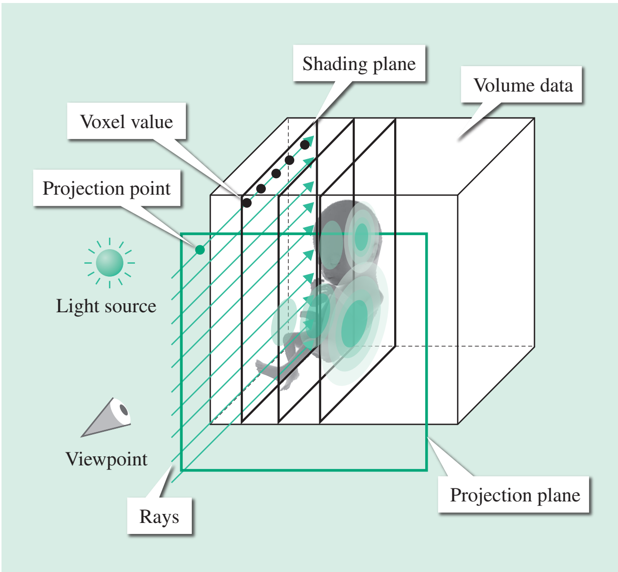

Fig. 5—Overview of New Rendering Method.
Rendering is performed by generating shading planes that replicate the scattering and absorption of light, and summing the product of this and the voxel values.

Fetus phantom supplied by Computerized Imaging Reference Systems, Inc.

Fig. 6—High-quality Rendering Technique.
The images were rendered using the previous technique (left) and proposed technique (right).

light to achieve natural shading [see Fig. 4 (a)]. The shading plane is generated by sequentially calculating the degree of attenuation with each unit length, the incident light from the surroundings, and the light emitted into the surroundings, with ray casting being performed by sequentially updating the shading plane from the light source direction (see Fig. 5). The shading plane is also generated for each wavelength emitted by the light source. This results in a different degree of attenuation in the light from the tissue surface for each wavelength[6] [see Fig. 4 (b)]. This technique is able to represent the deep reds (non-neutral colors) in shaded regions (dark regions) that are characteristic of the subsurface scattering of skin. Fig. 6 shows an example of rendering using this technique. As can be seen, this achieves better shading expression and more realistic display of 3D fetal images than the previous method.

Skin Color Correction

The color of skin is said to be something that people hold in their memory, and extensive research has been conducted into appealing skin color[7]. Having studied the relationship between how skin color is represented and the impression created by the fetus, Hitachi has developed a method based on machine learning that provides a technique for quantifying its subjective appeal.

The proposed method uses ranking learning based on deep learning[8] to assess the appeal of the fetus (see Fig. 7). Also, the subjective assessment and ranking of appeal is used to provide teaching data for learning. The proposed method consists of two steps. The first step is the automatic generation of characteristic quantities. This involves extracting several million small patch images at random from the collection of photographs of babies used as learning data, forming

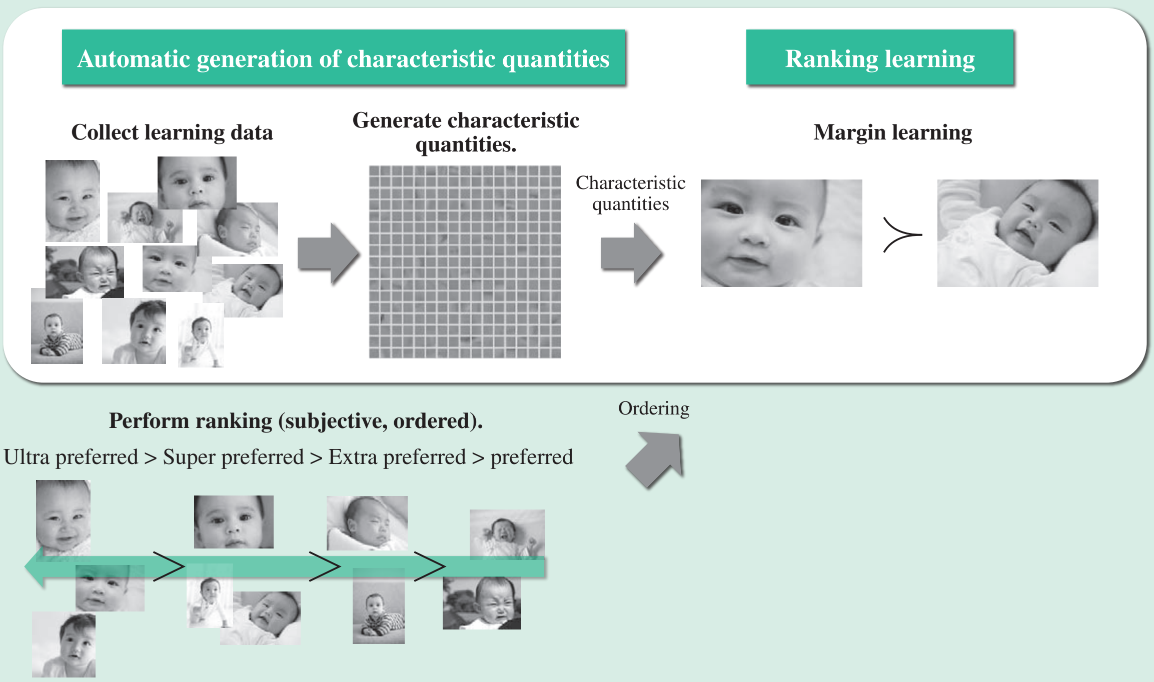

Fig. 7—Configuration of Subjective Analysis System Based on Deep Learning.
The analysis is performed in two steps: automatic generation of characteristic quantities and ranking learning.

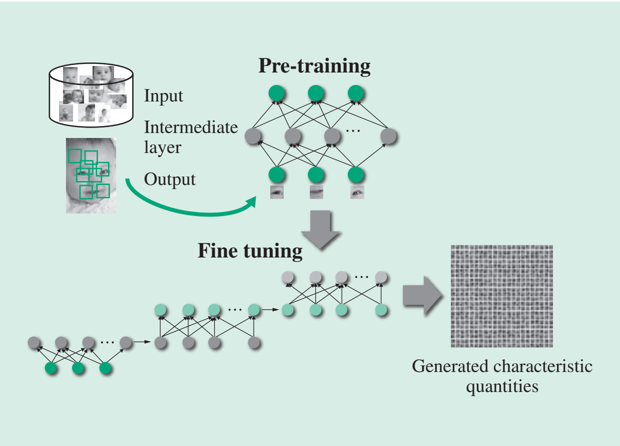

Fig. 8—Automatic Generation of Characteristic Quantities.
Learning is performed using multiple neural net layers to automatically generate highly abstracted characteristic quantities.

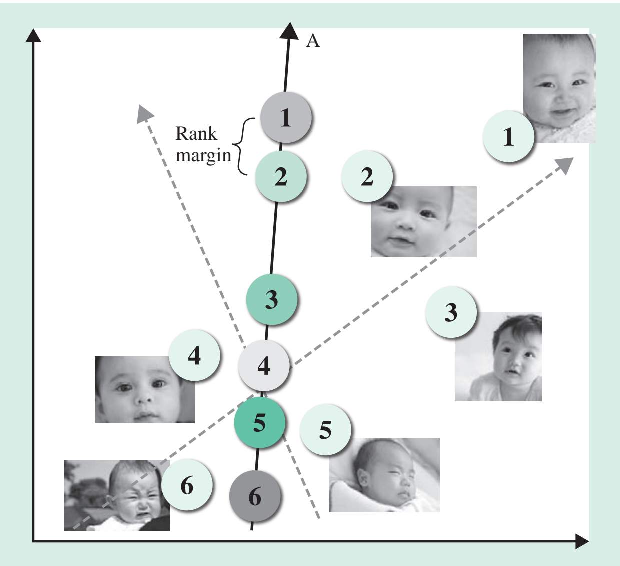

Fig. 9—Ranking Learning.
The A axis in the characteristic quantity space is set so as to match the rankings of the subjective results.

a neural net (NN) with a single intermediate layer, and conducting pre-training until the error between input and output is eliminated. Next, fine-tuning is performed using a number of stages of the above NNs to generate a vector of characteristic quantities with a high degree of abstraction (see Fig. 8). The second learning step consists of optimizing the ranking learning parameters so that the characteristic quantity vectors obtained for each image match the subjective assessment rankings. High accuracy is achieved through optimization involving margin maximization (separation) when ratings are higher or lower, and also margin minimization (joining) when the ratings are

TABLE 1. Learning Conditions for Automatic Generation of Characteristic Quantities
The table lists the learning conditions and parameters used in ranking learning based on deep learning.

Parameter	Value	Remarks
No. of images	400	Acquired from Google* Images*
No. of patches	9,000,000	Size: 6 × 6 pixels
Characteristic quantity	1,936 dimensions	
Total number of neural nets	5 layers	

* Google and Google Images are registered trademarks of Google Inc.

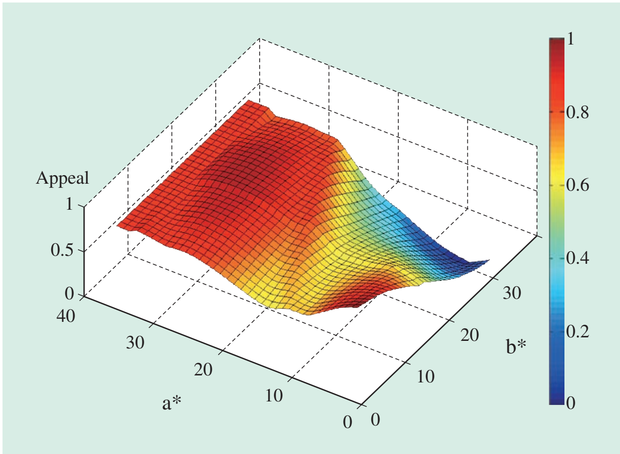

Fig. 10—Appeal Color Map.
The map indicates that red regions tend to have stronger appeal.

equal (see Fig. 9). For example, if photographs 1 and 2 in Fig. 9 are ranked as having the same degree of appeal and photograph 3 is ranked as having a lower appeal, the A axis in the characteristic quantity space is set such that photographs 1 and 2 are placed closer together and photograph 3 is farther away.

Table 1 lists the learning conditions.

When the performance of the subjective analysis system produced by this learning was assessed using 10-fold cross validation, it achieved an accuracy of 94% in identifying rankings up to the top 10.

Fig. 10 shows the appeal rankings produced when approximately 1,000 3D color fetal images produced by the high-quality rendering technique described earlier were input into the subjective analysis system with different values for the a* and b* parameters in the L*a*b* color space. These results show a tendency for redder skin colors to be more appealing. Drawing on these results, the attenuations needed to obtain appropriate a* and b* parameters for the display colors used in 3D images were calculated for each wavelength to produce four different skin color rendering patterns (see Fig. 11).

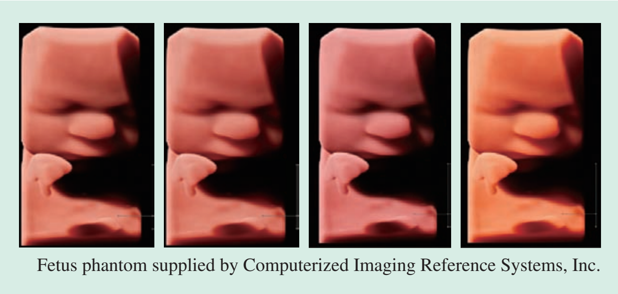

Fig. 11—Skin Color Rendering Patterns.
The patterns were generated based on the appeal color map.

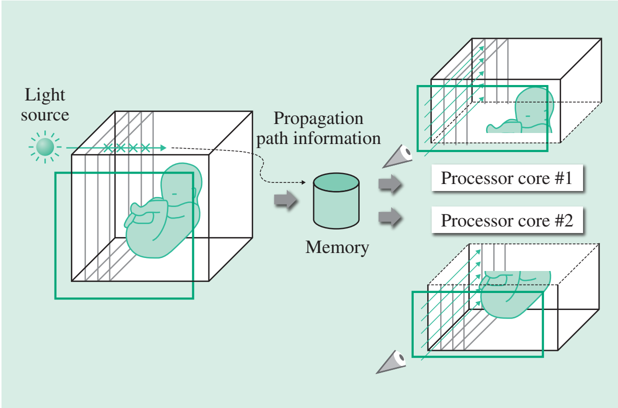

Fig. 12—Speed Increase through Pre-calculation of Path Information and Parallelization.
The calculation time was reduced by storing memory access information and by executing calculations concurrently.

Processing Speed Improvement

Hitachi Aloka ultrasound diagnostic scanners are fitted with high-speed, multi-core processors(9) to provide realtime rendering and display of 3D ultrasound images without the use of custom hardware.

However, the high-quality rendering calculation requires more than 10 times the processing time of the previous method. Accordingly, to achieve realtime rendering and display, the path information of light propagation is pre-calculated and the shading plane calculation is executed concurrently on multiple processor cores (see Fig. 12). The sequential calculation of the shading plane involves random memory access, which degrades the computational efficiency of the processor. To counteract this, the system achieves high-speed data access by storing path information in a way that enables efficient memory access, minimizing the memory access overhead by using this information in the shading plane calculation. Parallelization is also used to execute the shading plane calculation concurrently on multiple processor cores.

These measures have reduced the time required for the shading plane calculation to one-sixth its previous level, making it possible to perform realtime rendering and display.

EVALUATION AND RESULTS

This technology has been incorporated into cart type of ultrasound diagnostic scanners and the Noblus digital ultrasound diagnostic scanner*2, which went on sale in April 2013. These scanners feature a frame rate that is six times faster than the previous models, together with realtime rendering and display. They also allow the user to select from the four different ways of representing skin color described above.

The scanners have undergone clinical evaluation in actual medical practice, where they were favorably received by both clinicians and pregnant women.

The technology is used in all of Hitachi's ultrasound diagnostic scanners, from the top-end models to mass-market models. Its inclusion in the Noblus (see Fig. 13) in particular means that realistic 3D fetal imaging is now available in a portable ultrasound diagnostic scanner. Fig. 14 shows an example image produced using high-quality rendering techniques.

Fig. 13—Noblus Digital Ultrasound Diagnostic Scanner.
The Noblus provides realistic 3D fetal imaging in a portable scanner.

*2 Marketed as the Noblus advanced versatile ultrasound scanner. Medical equipment certification number: 224ABBZX00092000

Fig. 14—Example of Realistic 3D Fetal Image.
High-quality rendering techniques help achieve a 3D effect and more accurately expresses skin color and texture.

CONCLUSIONS

This article has described a highly realistic volume rendering technique and a skin color correction technique that produces appealing colors, techniques that deliver new value to clinicians who operate the ultrasound diagnostic scanners used in obstetrics and to pregnant women and their families who are the ultimate beneficiaries. This technology, which has been incorporated into three models of cart type ultrasound diagnostic scanners and the portable Noblus digital ultrasound diagnostic scanner, has earned a good reputation in medical practice.

The next step is the application of this technology to diagnosis. 3D imaging has already entered widespread use in obstetrics, and its uses are expected to expand further with the addition of new clinical possibilities. To provide the quality of images that clinicians require for diagnosis, it is important to provide the clinical benefits of displaying these images in three dimensions. With regard to image quality, improvements are being made to core image processing techniques such as higher resolution and noise suppression. Hitachi intends to further develop the shading expression technique described in this article to achieve more complex representation of light scattering and absorption, and to determine what these mean in clinical terms. Hitachi also believes that the subjective quantification technique described here for evaluating the appeal of images has the potential to quantify what good image quality means to clinicians.

Hitachi intends to continue using dialogue with the people who work in the medical field as the basis for supplying valuable solutions.

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