Abstract

Ultrasonography is attracting attention as a screening method with the potential to compensate for some of the problems with mammography. During ultrasonography, the investigator must reconstruct the three-dimensional shapes of the lesion and healthy tissue in his or her mind on the basis of two-dimensional video images, and he or she must therefore be skilled in perceiving three-dimensional images. We have developed a three-dimensional reconstruction training tool for use by practitioners of ultrasound screening. This system generates and displays cross-sectional images sliced in the x, y, and z orientations, on the basis of which the user must deduce the three-dimensional shape of the input model. As our goal is to train in three-dimensional perception, the input models in this system are letters of the alphabet, which can easily be used as analogy. We have developed it as a plugin for ImageJ, which is popular among medical professionals, with the aim of enabling its widespread use. Our proposed system not only displays cross-sectional images but is also capable of adding noise, varying contrast, and displaying video. In tests, it was evaluated by five specialist breast cancer doctors as being of potential use for training investigators. As an ImageJ plugin, it is highly versatile and can easily be introduced. We intend to test learning outcomes when this system is used as a training tool in the future in order to provide an objective evaluation, and to verify the types of images that are appropriate for training.

Keywords---Breast ultrasonography, 3D Training tool, ImageJ Plug-in

1. Introduction

Cancer deaths in Japan are increasing year by year, and the government is devising measures to combat this [1]. Breast cancer in particular is the most common type of cancer in women, who are at greater risk of dying from their 30s through to their 60s than from any other form of cancer. In recent years, a rising number of women have been developing breast cancer in their 40s, and improved methods of breast cancer screening are under consideration [2].

Under current government policy, mammography is the basic method of breast cancer screening. Diagnostic techniques using ultrasound devices have also recently been developed, but the effectiveness of ultrasonography for breast cancer screening has yet to be established. The Ministry of Health, Labour and Welfare has launched a comparative trial (J-START) as a government project to verify the effectiveness of ultrasonography in breast cancer screening, and studies investigating the effectiveness of the combined use of mammography and ultrasonography are currently underway [3-4]. Compared with mammography, ultrasonography offers the prospect of real-time diagnosis with good results for tumorous lesions and dense breasts. Because it is non-invasive, tests can be performed repeatedly, and it is useful for pregnant women and young test subjects. It also permits observations from any direction, enabling lesions to be assessed in three dimensions. It is for this reason that ultrasonography is attracting attention as a screening method with the potential to compensate for some of the problems with mammography.

During ultrasonography the investigator must reconstruct, inside their head, the three-dimensional shapes of the lesion and healthy tissue on the basis of two-dimensional images, and he or she must therefore possess three-dimensional perception skills. The narrow effective field of view in ultrasonography may result in lesions being overlooked, and
sensitivity may also be reduced by noise components; seminars and training in how to overcome these issues are therefore provided for practitioners who specialize in breast ultrasound. In such seminars and the field of training generally, however, teaching the spatial awareness required when interpreting images however, is extremely difficult [5].

Training model sets to improve technical skills in image interpretation for ultrasonography have already been developed [6-8]. Studies on the development of tools to foster spatial awareness are also ongoing, but at present no training tool exists for improving the image interpretation skills of practitioners who read and interpret the results of ultrasound screening.

We have developed a training tool for use in deducing the three-dimensional shapes of objects seen on two-dimensional video images, for use with breast ultrasound images, and evaluated its effectiveness as a training tool. Our goal is for medical staff to use the system we have developed to improve their image interpretation skills in ultrasound screening. This system has been developed as a plugin for ImageJ, a highly versatile program that is widely used in healthcare settings. We envisage that it will be used as an educational tool in practical training for students before starting work in the clinical arena.

2. Methods

2.1. Request from the Medical Education

The specifications and structure of our system were devised on the assumption that it will be used in on-site medical education. There are three main requirements for training systems for ultrasound screening practitioners in medical education, and are listed below.

The first is that any such system must be highly versatile, capable of being operated by users who do not possess any particular computer skills, and usable on a personal computer or similar device. Given the particular nature of medical education, it must be possible for image results to be output as video files, and for educators to use them in lectures as slides or similar materials. Use of this system should thus enable interactive teaching. Finally, the main functions of the system must constitute the production of three-dimensional models of shapes and of two-dimensional images comprising the various selectable cross-sections of those images. An observer using the system views a large number of two-dimensional cross-sectional images generated by the system, and deduces the original three-dimensional shape. The three-dimensional shape from which those cross sections were taken is finally displayed to the observer, who then views the cross-sectional images again. This process is an attempt to train the ability to reconstruct a three-dimensional shape in the mind from two-dimensional images that comprise cross-sections of a three-dimensional shape.

As this system is a tool for training in three-dimensional perception by imagining or envisaging the relationship between a three-dimensional object and slides in front of and behind it on the basis of two-dimensional images; it utilizes existing images such as shapes, hiragana characters, and letters of the alphabet, so that rather than looking for specialist anatomy or lesion characteristics, the observer can use it like a game. Rather than being a simple game or quiz, this system is graded into several different levels of difficulty, meaning that it provides a training tool at the level of ability required by medical professionals.

2.2. Overview of Our Proposed Method

As described in the previous section, we developed a training tool to meet the system requirements of a tool for training ultrasound investigators as part of medical education, as illustrated in Figure 1. Three-dimensional models previously constructed on a computer are used as input. The three-dimensional model input is virtually sliced to generate cross-sectional images. These cross-sectional images are displayed sequentially, forming a two-dimensional video that is watched by the observer using the system. The observer is then asked to deduce the physical three-dimensional shape on the basis of the video images. So that training can be carried out under conditions closely resembling those of actual ultrasound screening, users are able to carry out image processing themselves, varying the contrast of the viewing screen or adding noise to take account of the distinctive characteristics of breast ultrasound images.

Our proposed system has been developed as a plugin for ImageJ image processing software. ImageJ

![Flowchart of our proposed method](https://example.com/image.png)
has numerous image processing and image analysis functions as well as a user interface with clear analysis parameters, and is thus widely used in healthcare settings. By publishing our plugin we are enabling more medical professionals to undergo three-dimensional reconstruction training, as this system can be used by anyone in an environment in which ImageJ is installed. The plugin was developed with reference to the Volume Viewer (V. 2.01) plugin for ImageJ published by Dr. Kai Uwe Barthel at the National Institutes of Health [9].

2.3. Model Design
The system uses three-dimensional models constructed on a computer as input. These are three-dimensional models of letters of the alphabet, in raw 24-bit RGB image format. As our proposed system is a tool for training three-dimensional perception skills, and not for looking for specialist anatomy or lesion characteristics, it uses letters of the alphabet and other existing input models. Even for a known image, it can be difficult to deduce the three-dimensional shape when viewed from varying angles, and curved shapes such as the letter S shown in Figure 2 are particularly difficult. Letters of the alphabet are thus suitable shapes for use in training. Models of letters of the alphabet such as that illustrated in Figure 2 can easily be generated in ImageJ, permitting both users of the system and teachers to carry out training using their own models. In this study, we created 10 sample models of letters of the alphabet in ImageJ for use in checking the operation of the system.

2.4. Generation of the Cross-sectional Image
The input model is virtually sliced to generate cross-sectional images on a computer. This three-dimensional model is input as voxel data, with coordinate axes defined as shown in Figure 2, and cross-sectional images can thus be generated using the spatial information of each voxel. When generating cross-sectional images, even if the input model is a known image such as a letter of the alphabet it can be difficult to deduce the three-dimensional shape when viewed from varying angles, and the slice directions were thus restricted to the orientations of the three axes. Figure 3 shows cross-sectional images of a three-dimensional model of image size $400 \times 400 \times 100$ voxels, created by the authors to confirm the operation of the system. Figure 3(a) is a cross-sectional image sliced in the $z$ orientation at $z = 50$. Similarly, Figure 3(b) is sliced in the $y$ orientation at $y = 200$, and Figure 3(c) is sliced in the $x$ orientation at $x = 200$.

2.5. Image Processing
In our proposed system, users can add noise to the viewing screen or vary the contrast to take account of the distinctive characteristics of breast ultrasound images. We describe below the functions equipped in this training system with respect to noise and contrast.

2.5.1. Contrast Variations
In ultrasound screening, dynamic range and gain can be manipulated during scanning to adjust the image contrast. In our proposed training system, the contrast on the observation screen can be freely adjusted via the user interface, permitting users themselves to vary the level of difficulty of training. Figure 4 shows the observation screen before image processing and after contrast adjustment. A conversion table was provided to enable rapid processing when varying the contrast. The slope is calculated from the change in the value of the slide bar, and the pixel value is calculated for each pixel.

![Fig.2 Input model (voxel image)](image)

![Fig.3 Cross-Sectional Diagram](image)
2.5.2. Add Noise

In addition to the speckle noise generally evident in ultrasound images, our proposed system also incorporates a function for adding other characteristic types of noise: homogeneous noise, Gaussian noise, and salt-and-pepper noise. Figure 5 shows the observation screen after these different sorts of noise have been added.

Figure 5(a) shows an image with added speckle noise. Speckle noise is often evident in ultrasound images, and makes the image appear speckled. It occurs as the result of interference between reflected and refracted waves when ultrasound waves encounter cellular tissue. The amplitude distribution characteristics of the reflection echo from a homogeneous scattering medium such as healthy liver tissue can be closely approximated by the sort of Rayleigh distribution shown in Equation 1 [10]. In this study, we therefore added noise to the input images in accordance with this Rayleigh distribution to generate fake noise in these images, including speckle noise.

\[
p(x) = \frac{2x}{\sigma^2} e^{-\left(\frac{x^2}{2\sigma^2}\right)}
\]

(1)

\( p \) represents the probability density function, \( x \) is amplitude, and \( \sigma^2 \) is variance.

Figure 5(b) shows an image with added homogeneous noise. Homogeneous noise has the homogeneous distribution \([\alpha, \beta]\), and the probability density function is defined as shown in the following equation.

\[
p(x) = \frac{1}{\beta - \alpha}
\]

(2)

Figure 5(c) shows an image with added Gaussian noise. Gaussian noise follows the normal distribution \( N(\mu, \sigma^2) \) with mean \( \mu \) and variance \( \sigma^2 \), and the probability density function is defined as shown in the following equation.

\[
p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\left(\frac{(x-\mu)^2}{2\sigma^2}\right)}
\]

(3)

\( p \) represents the probability density function and \( x \) the amplitude.

Figure 5(d) represents an image with added salt-and-pepper noise. Salt-and-pepper noise is a form of impulse noise, in which white and black noise is added with equal probability to randomly selected images. In an RGB environment, white is represented as \((R,G,B) = (0,0,0)\) and black as \((R,G,B) = (255,255,255)\), and salt-and-pepper noise is therefore expressed by the following equation.

\[
Noise = \begin{cases} 
0; (p = 0.5) \\
255; (p = 0.5) 
\end{cases}
\]

(4)

3. Experiment

We thus developed a three-dimensional reconstruction training tool incorporating cross-sectional image generation, contrast variation, noise addition, and video display functions. We now move on to a description of its method of use and user interface.

3.1. Usage of Our Training Tool

As our training tool has been developed as an ImageJ plugin, it can be used by adding the training tool plugin to a computer already installed with ImageJ. The plugin is added simply by copying the
plugin file (.jar) to the ImageJ plugins folder in the ProgramFiles folder. Figure 6 shows an illustration of how to add the plugin. Once the plugin has been added, its name appears as the most recently added plugin at the bottom of the list under PlugIn in the menu bar. Clicking on this launches the newly added plugin.

3.2. User Interface

Figure 7 shows the user interface for our training system. Running the plugin opens the screen for input image selection, as shown in Figure 7(a). In this study, we prepared 10 models to use for confirming system operation, and the model to be used for training can be selected via this screen. Selecting an input model opens the main training tool screen shown in Figure 7(b). The cross-sectional images of the three-dimensional model selected for input are displayed in area 1 of Figure 7(b), and the user can view the images for observation as a video by clicking the buttons in area 2. The buttons in area 3 switch the display between the x–y, x–z, and y–z orientations, so the user can observe the video while varying the direction of observation, which provides them with training in deducing three-dimensional shapes. To vary the level of difficulty of the training in this study, noise could also be added to the images observed and their contrast could be varied. These functions were implemented using the buttons in area 3 and the slide bar in area 5 of Figure 7(b). These were user-operable, enabling them to vary the level of difficulty as the training progressed.

4. Results and Discussions

Through the research project reported here, we developed a three-dimensional reconstruction training system with specifications based on the requirements of medical education. This system incorporates the functions described above, meeting the requirements of breast specialists, and has been positively evaluated by five specialist breast doctors. As the system has been developed as an ImageJ plugin, it will be distributed together with 10 sample models. No other software need therefore be installed in order to use this system for training, making this a highly versatile system that can potentially be used easily by many medical professionals. As it utilizes letters of the alphabet as input models, their three-dimensional shapes are easily deduced by analogy. It may therefore be useful as a training tool not only for screening staff and doctors, but also for students before starting work in the clinical arena.

We have enabled noise to be added to images for observation and the contrast to be varied in our
training tool, but we have not yet evaluated whether or not the image quality of images with added noise or varied contrast is actually similar to that of breast ultrasound images. In ultrasound screening, it is possible not only to vary the contrast but also to adjust brightness and edge strength by manipulating imaging parameters. It may therefore be necessary to adjust the image quality to match that of actual breast ultrasound images, taking account of these imaging parameters. As our system is solely a training tool for the deduction of three-dimensional shapes, however, it may not in fact be a good thing for them to bear too close a resemblance to actual breast ultrasound images. It will therefore be necessary to test the learning outcomes achieved with the use of our training tool, and to produce images and add functions that are appropriate for use in training.

5. Conclusion

We have developed a tool to train practitioners of ultrasound screening in deducing three-dimensional shapes from two-dimensional videos. This system has been developed as an ImageJ plugin, making it highly versatile, and it may be a useful system for students before starting work in the clinical arena. As the specifications and structure of our system have been designed in response to the requirements of healthcare settings, it has received a positive evaluation from five specialist breast doctors.

We intend to add a video output function in the future, with a view to enabling interactive teaching. In order to objectively evaluate whether or not this provides an effective training tool for ultrasound technicians and doctors, it will be necessary to assess the educational effects of training by means of this system.

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