A Registration Between 3D Ultrasound Images and 3D Fetal Model for Locating a Fetal Mouth in a Fetal Surgical Navigation System

Rong Xu1, Jun Ohya1, Bo Zhang2, Yoshinobu Sato3, Masakatsu G. Fujie2

1. Introduction

Congenital diaphragmatic hernia (CDH) is a severe defect, has a prevalence of 1 in 2,000-3,000 newborns. The outcome of fetuses with CDH may be improved by fetal endoscopic tracheal occlusion (FETO) with a balloon, and a minimally invasive surgery (MIS) is operated for FETO to position a balloon into fetal trachea by the navigation of 2D ultrasound images and fetoscopic images [1, 2]. This surgery is so difficult that autonomous surgical supporting systems (for inserting a surgical tool into fetal mouth and trachea) are desired to be actualized.

3D ultrasound (US) images are very useful for FETO surgery, but due to speckle noise, shadows, attenuation, signal dropout and low resolution, the anatomy of fetal oral cavity and airways cannot be distinguished clearly from 3D US images, as shown in Fig. 2 (a). On the other hand, the anatomy of fetal airways can be visualized by MR or CT images; however, no work on the reconstruction of 3D model with fetal airways from MRI or CT can be seen, and also there is no available product of 3D fetal model with fetal airways at present. In this paper, we reconstruct a 3D fetal model, and register it with the extracted 3D surface of a fetal face from 3D US images by iterative closest point (ICP) algorithm, and help localize the position of fetal oral cavity and airways for FETO surgery. First of all, one point cloud is extracted from 3D fetal model, and another point cloud is acquired from 3D US image by the edge detection we propose in this paper.

Then through the registration, the anatomy of fetal oral cavity and airways in 3D fetal model, which cannot be distinguished clearly by 3D US image, can be visualized and localized in 3D US space.

2. 3D Fetal Model

The surface of 3D fetal model is created by scanning a fetal phantom with an untouched high-speed 3D scanner - 3030RGB/MS, as shown in Fig. 1 (a). First, the phantom is made to stand on the front of the scanner. Next, the rotating platform with the phantom rotates a complete circle, and each turn is set to 10°. Then, we can reconstruct a 3D fetal surface by a point cloud data obtained from the untouched 3D scanner in Fig. 1 (b).

![3D fetal model](image)

Fig. 1. 3D fetal model. (a) fetal phantom, (b) 3D fetal surface, (c) design of fetal oral cavity and airways, (d) 3D fetal model with oral cavity and airways.

There are three parts in the anatomy of fetal oral cavity and airways: (1) oral cavity and pharynx; (2) larynx and trachea; (3) esophagus. Because the FETO surgery is operated at about 23-29 weeks gestational age (GA) [1], thus we select the average size for each part at about 23-29 weeks GA. These structures [3, 4] are drew by Solidworks 2008. To simplify the design, the cross sectional shapes of all tracts are considered as ellipse or circle. The size of each part has been marked out in Fig. 1 (c) based on the reference values in [5-9]. Through the rotation and translation in 3D space, we can obtain a 3D fetal model with fetal oral cavity and airways, as shown in Fig. 1 (d).

3. 3D Rigid Registration

3.1 3D Fetal Surface Extraction

In experiments, we scan a fetal phantom made by silicone resin in a water tank, via a Philips iU22 US system with a V6-2 probe to obtain 3D US image, as shown in Fig. 2 (a).

As we know, unlike MR or CT imaging technology, 3D US image does not have high resolution, as well as the transmission and reflection of ultrasound are easily affected by phantom material and air bubbles in water. Therefore, it is difficult to achieve a 3D US image with clear boundaries of fetal face surface. Owing to the low contrast of 3D US data, we select the slices on X-Y plane from Z = 100 to Z = 170 with relative clear edges of fetal face surface. In Fig. 2, (a) is a 3D fetal US image, (b) is the extracted slice of Z = 130. According to these slices, we find there is just front half of 3D fetal face surface in 3D US data, and accordingly our object is to extract this part from 3D US data. The processing of 3D fetal face surface extraction is described in the following steps and Fig. 2. Here, we take the extracted slice of Z = 130 as an example in Fig. 2.

Step 1 The boundaries of the 2D US slice are detected by canny edge detection, as shown in Fig. 2 (c).

Step 2 The ellipse is detected from Fig. 2 (c) by an improved iterative randomized Hough transform proposed in [10]. Then we get five standard parameters [x0, y0, a, b, φ] of the detected ellipse. Based on these parameters, we can estimate a region of interest (ROI) as a rectangle, where the center of this rectangle is set to the center of the ellipse (x0, y0), the width and height of this rectangle are set to a * 1.1 * 2 and b * 1.1 * 2 . Because there is no boundary at the back of fetal head in US data, the ROI is moved up slightly (here, we move it up by 50 pixels) in order to be applied for all selected slices, as shown in Fig. 2 (d).

Step 3 The area in the ROI is selected as shown in Fig.2 (e), and then is thresholded into Fig. 2 (f).

Step 4 The pixels in the fetal face surface in Fig. 2 (g) are separated as the largest connected region by a label filter (itk::LabelShapeKeepNObjectsImageFilter) in [11].

Step 5 Binary morphologic closing and opening are operated to smooth the binary result in Fig. 2 (h).

Step 6 The smoothed result in Fig. 2 (h) is scanned from top to bottom, left to right and right to left, and then the red edge of the fetal face in Fig. 2 (i) is distinguished.

![3D US Image](image)

![Extracted slice](image)

![Detected edge](image)
4. Conclusions

In this paper, we realize the rigid registration of two point clouds by the ICP algorithm for FETO surgery, where one point cloud is extract from the 3D fetal model with oral cavity and airways we reconstructed, and another point cloud is extracted from 3D ultrasound image. Through the registration, we can easily confirm the position of fetal oral cavity and airways in 3D ultrasound space. The experimental results demonstrate the registration between 3D fetal model and 3D ultrasound image is quite reliable for visualizing the position of fetal oral cavity and airways in 3D ultrasound space. In the future, we will introduce a 3D ultrasound calibration system to localize the position of fetal oral cavity and airways accurately.

Reference