The Fetouch System: Visual-Haptic Rendering of Fetuses

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Abstract. The system, developed at Siena University in the last two years, allows users to haptically interact with 3D models obtained from ultrasound scans. Its current prime use is to allow mothers to interact with a model of the fetus they are carrying. The system, which is freely available on the project web page (http://www.fetouch.org), has been tested on twelve cases which have been monitored by doctors at Siena Hospital. New features of the system include the haptic heartbeat feature.

1 Introduction

In the last twenty years ultrasound techniques have grown in popularity among the gynecology and obstetrics communities [1,10]. Ultrasound technologies have become a standard in detecting several morphologic and functional alterations involving both fetus and internal female genitalia. The success of ultra-sonography is mainly due to its non invasive nature, low cost and ease of use.

The visualization process for ultrasound scans is normally based on rendering the 3D volume on a standard 2D PC monitor. While this process has proven quite effective it remains somewhat limited. Depth information is partially lost. Furthermore no physical interaction is allowed. One of the possible ways to enrich the fruition of 3D volumes, one proposed in this paper, is based on the use of haptic devices.

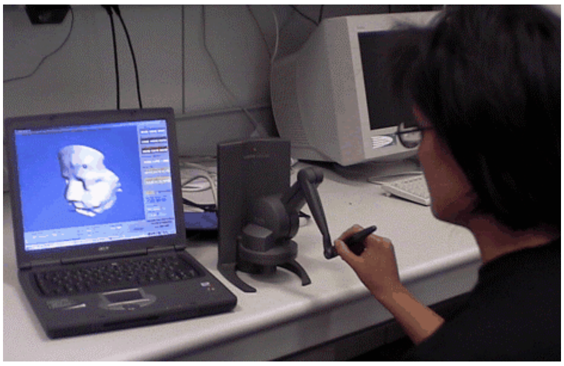


Fig. 1. The Fetouch workstation.

It is important to note that the system has not been designed with medical diagnosis in gynecology and obstetrics as a prime focus. The user interacts with the surface of a 3D fetal model (or other model). While such surface is enhanced with various effects, such as compliance, heart beat and skin texture it is important to note that none of these effects are physically based on the data obtained from the ultrasound machinery.

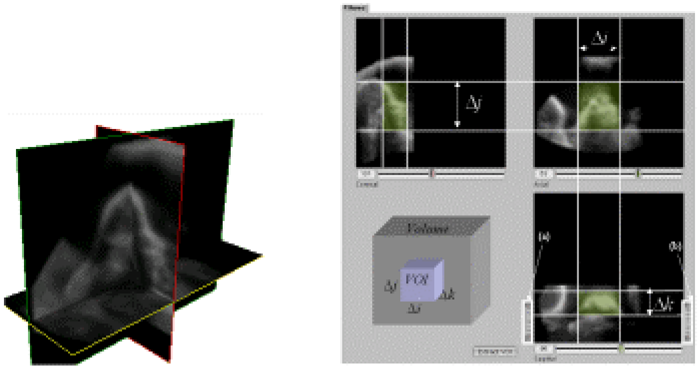
In recent times Novint Technologies has announced the release (at the end of 2002) of a commercial product, the e-Touch Sono, which allows users to interact with 3D fetal models [7]. While the idea is similar to the one proposed in [7], differences exist. The Novint product will be based on a dedicated 4D Ultrasound System produced by GE (the Voluson 730 4D Ultrasound). This will certainly ensure a high level of quality but will limit the application to a specific 3D type of ultrasound systems. By using ultrasound 2D-scans in the DICOM standard the system [5] can be used with data obtained using any ultrasound machinery.

2 System software architecture

The system is divided in two main blocks serving different functions. The first block (US3D) is devoted to creating a 3D visual-haptic model give a set of ultrasound scans. The second block (US3Dtouch) allows the user to interact with such system using a haptic device (PHANTOM[12] or Delta[2]) and a 3D image (PC screen alone or enhanced by stereo glasses).

Software has been designed in C++ in an object oriented setting and is portable on various platforms (e.g. Windows and Linux). The Visualization Toolkit (VTK) has been used [9] to create a visual feedback to the user as well as for performing collision detection between the user and the 3D fetal model. The Graphical User Interface has been developed with the fast light toolkit (fltk)[11]. In the following we will focus our attention on the two main blocks that make up the system.

The US3D subsystem allows ultrasound 2D-scans, in DICOM format, to be gathered and displayed as a volume. In order to better visualize the ultrasound volume, data is re-sliced along three directions (axial, sagittal and coronal) as shown in Fig. 2(a).



(a) (b)

Fig. 2. (a) The axial, sagittal and coronal visualizations of the fetus; (b) Selecting the volume of interest (VOI).

A direct visualization of the ultrasound volume is available in US3D. The Maximum Intensity Projection (MIP) approach is used to render the image. This technique of direct volume rendering, also known as ray-casting, is based on drawing parallel rays from each pixel of the projection screen and then considering the maximum intensity value encountered along the projection ray for each pixel [4]. This method does not need any pre--processing phase and is fast but it is not truly a 3D visualization technique since any information on depth is lost. The noise affecting raw data can be filtered by a 3D Gaussian smoothing kernel. The volume of interest (VOI) can be selected using the GUI of the US3D software, see Fig. 2(b).

The VOI is first segmented from the background to obtain, by means of a threshold filter, a binary volumetric data set. The surface fitting algorithm known as marching cubes, designed by Lorensen and Cline [6,9] to extract surface information from 3D field of values, is then used to render the model isosurfaces. The surface is constructed according to the following basic principle: if a point inside the desired volume has a neighboring point outside the volume, the isosurface lies between these points. This analysis is performed at the voxel level.

The US3DTouch subsystem is in charge of recreating physical interaction with any fetal model extracted using the US3D software. The standard proxy and god--object algorithms [8,13] have been implemented and tested on various fetal models. It is important to note that the number of triangles making up any fetus scan can be considerably reduced. Fast collision detection algorithms are used. More specifically OBB-tree [3] are used to make the process faster. Note that this is made simpler by the fact that, even though the fetal model feels compliant to the user, interaction forces are computed using a static shell representing the fetus.

Various visual and haptic effects are added to the fetal model in order to make the overall simulation more realistic. More specifically a heart--rate effect is haptically simulated. The mother's heart--rate is measured and decomposed in various sine waves. The heartbeat signal is directly acquired from the fetus. A pre-processing phase adapts the heartbeat signal to the haptic rendering system. In particular, the signal is filtered and the Fourier analysis is used to extract the low frequency components. The heartbeat signal is rendered by simply adding the pre-processed signal to the normal force of the surface haptic rendering procedure. The amplitude of the heartbeat signal is scaled according to the distance from the hearth area of the virtual fetus. The hearth area is defined by the user in the initialization phased of a system session.

The visual feedback is greatly improved by using graphical textures obtained by pictures of new born babies. Similarly haptic textures are added to the fetal model in order to make its surface feel like human skin.

3 Current limitations and future work

As previously mentioned the current system has been created as a tool for mothers to better interact with 3D models of their fetus and not as a diagnostic tool. While this is an incredibly fascinating prospect, it is far from being a reality. Various challenges must be met in order to solve such problem. In the future we plan to user deformable objects techniques to simulate the fetus model using standard compliance values found in literature.

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