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Three-Dimensional Obstetric Ultrasound for the Developing World

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Three-Dimensional Obstetric Ultrasound for the Developing World

Abstract

The imaging modality of three-dimensional (3D) ultrasound has been available for a few decades. In obstetrics, its value in assessing fetal development is appreciated by medical practitioners. However, its utility has not been widely adopted due to its relatively higher cost. The main disincentive in the application of 3D ultrasound is the increased costs incurred by the patient, as insurance companies largely elect to cover only 2D imaging expenses, citing lack of increased medical value for the patient. Additionally, the prohibitive initial cost of 3D-capable ultrasound machines essentially removes this powerful medical technology out of reach of many in the developing economies. During pregnancy, assessment of fetal development is crucial in ensuring its healthy growth and development, including overall maternal health. This is especially the case in the poorest countries, where infant mortality rates are still very high. In an attempt to address this form of medical marginalization, a hybrid system is interfaced with a regular 2D ultrasound machine in the collection of 2D images that are then translated to 3D by external reconstruction software.

As with many computer engineering programs, students of the computer engineering program at Utah Valley University (UVU) conclude their degree programs with a semester capstone design experience. The intent is for students to utilize competencies developed in the first three years of the curriculum in the solution of an embedded design problem. This paper summarizes the result of an undergraduate capstone experience where the feasibility of utilizing ubiquitous technology (2D ultrasound) to mimic the functionality of enhanced but expensive 3D ultrasound machines is assessed.

Capstone Projects at UVU

The goal of projects in our Capstone Design course is to provide our students with a realistic design experience and to teach them the tools and methodologies that can help them to be successful. Our senior design course is structured as a collection of independent student projects. This course is offered every semester. The students in the Computer Engineering program take this course during their last semester. Students either can come up with a project themselves or work on a project that is given to them by their advisors. Students write a proposal to define problems and identify solution approaches for their project and the hardware and software that is needed for their project. After several iterations, the advisor approves their project proposal. Then, they start working on their projects. Students are required to write weekly progress reports and meet with their advisor during a weekly scheduled time for each student. At the end of the semester, they turn in a final written report and a final presentation which is evaluated by several faculties from the department.

Introduction

Ultrasonography is a medical imaging technique that uses high frequency sound waves to observe internal physiological phenomena and accurately make diagnoses. Ultrasound imaging provides a cheaper, safer, and noninvasive means for performing medical diagnoses.

In obstetrics, extensive research has shown numerous advantages of 3D ultrasound: Improved maternal/fetal bonding[1] and identification of fetal anomalies[2] due to improved visualization of fetal features; and more accuracy in volume measurement [3], aiding in management of the pregnancy and in determining the size and extent of the anomaly. Gender determination using 3D ultrasound has also been shown to be more accurate than 2D ultrasound[4]. Furthermore, the feasibility of 3D ultrasound guided surgery has also been assessed, underscoring its value in medical diagnoses and treatment[5].

In assessing fetal development, ultrasound images are usually collected by an ultrasound technician placing the ultrasound probe/transducer on the patient's abdomen and moving it in a desired fashion, in an attempt to focus on the desired fetal anatomical region only. The ultrasound technician then attempts to mentally reconstruct the 2D planar images to create a 3D mental visualization of the fetus. This technique is error-prone, especially with a poorly trained ultrasound technician or a novice. However, in 3D ultrasound, even novices have been shown to be able to easily reproduce fetal biometric measurements with accuracy that parallels an experienced ultrasound technician's[6]. The latest ultrasound machines are capable of performing 3D reconstruction using specialized 2D phased array transducers. However, their high costs make 3D ultrasound less appealing, and, consequently, reduces 3D ultrasound's adoption.

The goal of this research was to determine the efficacy of interfacing the ubiquitous linear array ultrasound transducer with a hybrid electromechanical system in the collection of 2D images that are later converted to 3D using reconstruction software. It is also worth noting that this research was undertaken as an undergraduate senior design project. Informed consent was obtained from all research participants. This research was also approved by the Institutional Review Board.

Description of CAD

SolidWorks (Dassault Systems, MA, USA) Computer Aided Design (CAD) software was utilized in designing 3D components of the apparatus that would allow for a seamless adjustment in orientation and positioning of the transducer in accordance with the contours of the abdomen. The designed parts were then fabricated by a 3D printer. The custom-designed electromechanical system is a combination of off-the-shelf hardware components and CAD-developed, 3D-printed parts.

In designing the system, it was imperative that the apparatus that held the probe be able to automatically adjust the probe's altitude as it traversed the changing contours of the abdomen while capturing 2D ultrasound images. It was also crucial that the system continuously align the probe in a perpendicular fashion with the abdomen's surface to ensure maximum contact which yields minimal signal attenuation.

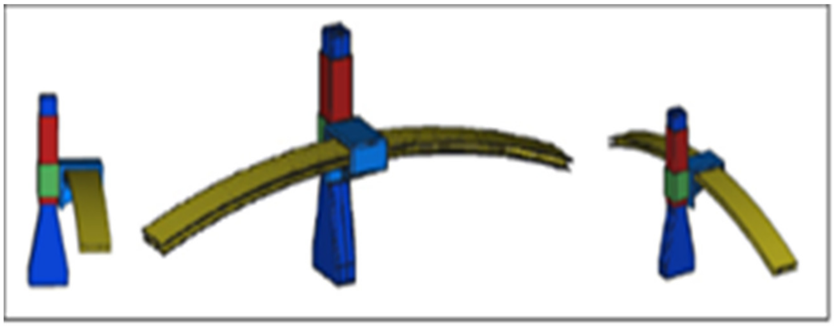

Fig 1. 3D components created via CAD

The prototype is shown in Figure 1 and final assembly in Figure 2. The probe is firmly held inside the probe holder (blue part) and the holder is free to move freely inside its housing (red part). The green part is attached to the middle shaft of an X-Y plotter. The holder is attached to the arch, which is itself attached to the X-Y plotter. Two 2-phase stepper motors precisely control the speed at which the probe moves along the arch along the X-Y planes. The system is driven by an Arduino Uno microcontroller.

Fig 2. Final assembly of hybrid system.

It can be seen from Figure 2 that the transducer will be able to move freely along the Z-plane as it traverses the X-plane and the Y-plane. Deformable modeling[7] was applied in the rare occasion when the ultrasound technician manually intervened in order to collect images at steep angles that exceeded the hybrid system's maneuverability. However, since the X-Y translation of the probe is always along straight lines, the application of these deformable algorithms to correct for arbitrary movements caused by manual handling of the ultrasound transducer was limited.

Algorithms and Simulation

The two major image rendering schemes employed in medical imaging are multi-planar reformatting (MPR) and volume rendering (VR)[8]. Medical images are usually in the Digital Imaging and Communications in Medicine (DICOM) format, a standard for handling, storing, printing, and transmitting information in medical imaging[9,10]. Images generated can vary, depending upon different factors including: positioning of the fetus, amount of amniotic fluid present in the womb, fetus' gestational age, and the mother's body habitus.

Images were collected using a General Electric Logiq 7 ultrasound machine (General Electric, CT, USA). Fig 3 shows a sample 2D scan from the machine. The Cine Loop functionality of the ultrasound machine was capitalized upon to collect images. This meant that no extra hardware and software was needed to keep track of the time and position in which the images were collected[11]. The constant speed at which the probe traversed the belly ensured that the 2D planar images were evenly spaced. The images were collected using a curved array transducer at 4 MHz; a relatively low frequency that scans much deeper into the abdomen but offers less resolution. A low frequency scan is preferred for obstetric ultrasound.

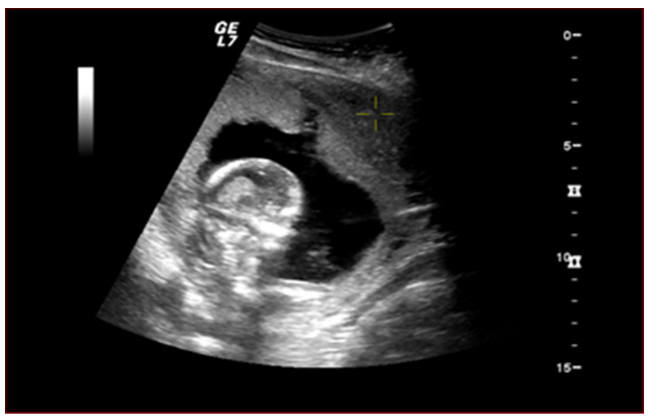

Fig 3. A MPR axial view of a 12-week fetus.

Ultrasound images are generally noisier relative to other modalities such as computed tomography (CT), and magnetic resonance imaging (MRI)[12]. This inherent noise necessitates the employment of filtering techniques to assist with noise reduction and improve image quality[13]. Median filtering and Gaussian filtering were applied to improve image quality. The kernel radius was set to one.

As Fig 4 clearly demonstrates, filtering helps with improved image quality. The salt-and-pepper noise that is characteristic of ultrasound scans make the images especially suitable for median filtering. A parallelized version of an optimal median filter—time complexity of O(1)—was implemented to de-noise the image[14].

Fig 4. A median-filtered ultrasound image.

While a median filter might be preferred for removing salt-and-pepper noise, this improvement is mainly appreciated in 2D images. For 3D rendering, Gaussian smoothing produces higher quality images. The Gaussian filter lessens the contrast of edges, which provides for a much improved overall 3D rendering, as can be seen in Fig 6. The median-filtered image in Fig 5 and the Gaussian smoothed image in Fig 6 clearly demonstrate this contrast. Note the overall smoother texture of the Gaussian smoothed image as compared to the median filtered one.

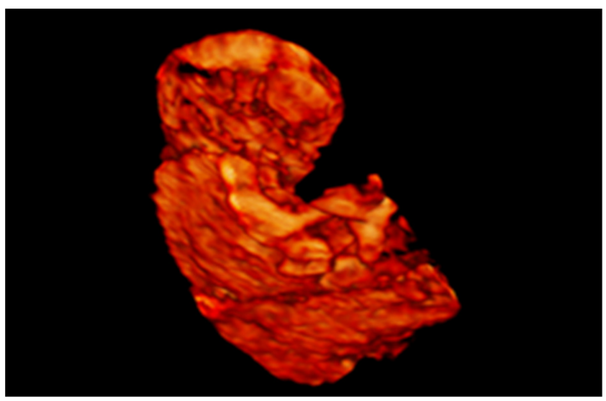

Fig 5. A 3D view of a median-filtered image.

Discussion

NovaPACS (Novarad Corp., UT, USA) software was used to perform 3D reconstruction of the image data collected by the ultrasound machine. Images were collected from two volunteers at 12 weeks and 21 weeks of gestation. The ideal time-frame for optimal sonographic view of the developing fetus is between 15-21 weeks of gestation[15].

While 3D ultrasound may provide several significant advantages over 2D ultrasound, it is not without challenges. The quality of the rendered images is highly dependent upon the positioning of the fetus[16]. For example, in this study, the ultrasound image data of a 21-week fetus was rendered unusable because its overall orientation was toward the maternal spine. Its physiological features were thereby poorly visible. Additionally, 3D ultrasound images later in the second and third trimester stages may be of sub-optimal quality due to diminished amounts of amniotic fluid which plays a big role in overall image quality.

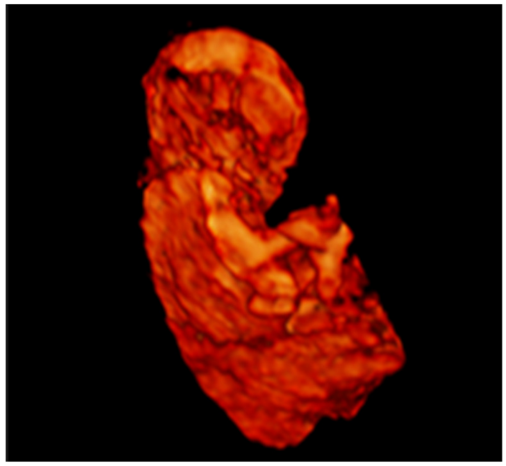

Fig 6. A 3D view of a Gaussian-filtered image.

In situations where the fetus is well positioned but the view is obstructed by fetal or maternal anatomical features, manual manipulation of the transducer coupled with extra 3D reconstruction algorithms may be necessitated[17]. In this research, deformable modeling was applied.

Conclusion

3D obstetric ultrasound has been shown to be possible via interfacing the ubiquitous 2D ultrasound machine with appropriate hybrid system. This interfacing significantly lowers the initial cost that would have been incurred in the procurement of 3D-capable ultrasound machines.

Furthermore, this research project was undertaken as an undergraduate senior design project, with minimal resources, including hardware and time constraints. With more time, the system's design could be further refined and the software algorithms' capabilities increased. With these improvements, the hybrid system's overall effectiveness and feasibility may become even more appealing.

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