Full title:

3D Augmented Reality Simulator for Neonatal Cranial Sonography

Short title:

AR Simulator for Neonatal Cranial Sonography

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Summary

We are presenting *CranUS*, a simulator for neonatal cranial sonography. Its main purpose is to support teaching and training of a method of examination used in child radiology, that depicts the inside of a baby's skull by viewing through the fontanelle using ultrasound signals. This paper describes the concept and the implementation of that augmented reality supported 3D simulator, which is – to the best of the author's knowledge – the first one for this kind of examination. Physical models of a newborn and an ultrasound probe were tracked and their movements displayed in their virtual representation. The head of the newborn model was augmented with a 3D volume, reconstructed from ultrasound images of a real patient. *For examination of newborn children, no tracking information of the patient can be acquired. The volume therefore has to be reconstructed without exact knowledge of the slices positions/orientations.* Reconstructing a 3D volume from irregular source data requires positioning the images and the subsequent interpolation. When moving the physical models with respect to one another, the corresponding slices are generated in real time. The actual slice is shown on the 2D user interface, beside an image displaying the corresponding position of the models and additional visualization and tracking information. A prototype of the application was presented to the interested research community and thereby evaluated for its suitability as a training tool.

3D Augmented Reality Simulator for Neonatal Cranial Sonography

Introduction

In child radiology, neonatal cranial sonography is done on the head of a newborn as a precaution and for general diagnostic purposes [1]. The average human skull is closed after the second year and its bone material will block most attempts at sonography. The skull of a newborn has openings, known as the fontanelles. These fontanelles are used as acoustic windows, allowing the application of ultrasound, as the least harmful method of radiology for diagnostics in a very sensitive situation. Sonography on newborns are primarily done through the anterior fontanelle.

The physician holds an ultrasound probe to the head of the newborn. By positioning and moving this probe, the sonogram will be displayed as a two dimensional plane through the brain of the patient. The picture is shown as a grayscale image on a monitor, while the intensity of the ultrasound echo is translated into brightness and displayed as the sonogram. An optimal sliced view is necessary to acquire maximum information from the image. Positioning and handling the ultrasound equipment in a manner to get the optimal slices requires training. Until now this training could only be done either as theoretical training using books and image collections, or as a real sonograhy.

Figure 1: Neonatal cranial sonography [courtesy M. Riccabona, "Kinderradiologie", LKH Graz]

Currently there is a lack of sufficient training for this type of examination for radiologists. This deficit has lead to the project of a training environment, where radiologists can learn and practice neonatal cranial sonography without a real patient but still under most realistic circumstances. Using an augmented reality system allows the delivering of a realistic feedback to the handling of ultrasound equipment in a training situation.

Related Work

Only for a newborn, ultrasound is an appropriate method of medical diagnostic because of the still opened fontanelles. Because of the particularity of this situation, so far no ultrasound simulator for the brain of newborn has been developed.

A project involving Augmented Reality in medicine is the visualisation of brain structures done by Maurer et al. [2]. This approach uses a video see-through head mounted display (HMD) to visualize brain structures on a phantom head, to allow image-guided neurosurgical planning and navigation. Preoperative tomographic images will be used to generate virtual 3D objects by segmenting certain parts of those images. An approach by Hinckley et al. [3] describes the training of user skills for manipulating tools with two hands. A miniaturized head is used to apply movements of specially created tools. A cutting plane selection tool and a stylus like trajectory prop permit actions to be performed whose virtual impact will be displayed on a screen.

In other medical areas, ultrasound is commonly used because of the non invasive, non radioactive particularity of the technique. There are different approaches to using ultrasound or ultrasound images to support medical education and training. Henry et al. [4] describe an ultrasound imaging simulator to support training of physicians in detecting venous thromboses of the lower limbs. In this system a line of real ultrasound slices is used to support the generation of virtual ultrasound

images by interpolation between that slices. Their method of interpolation has been derived from an approach by Lengyel et al. [5] describing a 3D reconstruction and volume rendering of ultrasound images. Another approach describe by Berlage et al. [6] shows how a virtual 3D model can be used to obtain proper orientation for an ultrasound image. A model of the human heart and its movements are used together with a virtual representation of a probe to mimic the situation of an ultrasound examination and to show slice images. Ngo et al. [7] describes the use of specially prepared phantom heads and a real ultrasound device as used on a real patient. This approach de facto simulates the patient, by preparing a phantom using special material and its effects. Comparing the latter two approaches demonstrates two extremes on the scale between the most realistic approach possible, avoiding the use of real patients and the most virtual approach, where even the ultrasound pictures are synthesised. A setup to train biopsy needle insertion is described by Magee et al. [8]. A torso used as a training model is aligned with the surface data of a 3D volume created from computer tomographic scans. Mockup ultrasound probe and biopsy needle are connected each to a positioning sensor. Comparing the position of these props towards the phantom, virtual ultrasound images are calculated from the volume data set, which allows controlling the movement of the biopsy needle. The commercial real-time ultrasound imaging simulation system *"UltraSim"* is described by Aiger and Cohen-Or [9]. In an offline preparation process, a 3D volume is created from real ultrasound images. During the simulation this volume will be sliced and simulated ultrasound images are displayed accordingly. The chassis of a real ultrasound device is used with the probe attached to a positioning sensor. By moving this sensor across a real sized phantom the system generates virtual ultrasound slices from the volume data. Additional setups for different examination types can be created, by precalculating different volumes from real ultrasound scans. Multiple volumes can be used to construct a bigger composed meta-volume.

Another area of research is focused on the reconstruction of a 3D volume out of the source material from ultrasound. Aiger and Cohen-Or [9] describe, how a volume can be generated, which is used later to view slices from different directions. There are a number of specifics connected with the resampling of 2D ultrasound images. Compared to other methods of acquiring image material, an ultrasound examination is typically done by manually moving the hand probe over the area in question. The result consists of a number of nonlinear, nonequidistant images, which are partly overlapping.

To position the images into the volume, the data recorded from a position sensor on the probe is taken into account. Finally the reconstruction of the 3D volume needs an appropriate interpolation methods to achieve the wanted volume. Several papers in the past have described this challenge [10], [11]. The nearest neighbour method is the most common interpolation method [12], [13], [14]. It fills a voxel with the value of the nearest pixel from an image, and multiple contributions are typically weighted. Distance weighted interpolation takes into account the size and shape of neighbouring pixels of images and assigns a weighted average value to each voxel. The weight can be calculated by different approaches [12], [15]. The spherical approach, described by [12], calculates the weighted value of the spherical neighbourhood centered around a voxel. The weight is calculated by the inverse distance and then averaged. A non spherical approach considers the asymmetry of the ultrasound beam by applying algorithms to generate a range of different weights to calculate the final value of an interpolated voxel [16]. Considering the fan-shaped alignment of sonograms, an interpolation on a radial basis function, [10] appears to be promising. The path of interpolation describes a circle through the scans orthogonal towards their plane.

Implementation

The simulation is intended to help teaching radiology students to perform neonatal cranial sonography without a real patient. Its intention is to deliver a life-like environment as closely as possible. The main purpose of such a training, is to learn how to position and angle an ultrasound probe on the anterior fontanelle, to achieve the appropriate images for diagnostic situations.

The setup of *CranUS* includes the phantom, the hand piece, the tracking system and a computer with all the needed simulation and displaying software (*Figure 2*).

Instead of the real patient, a phantom is used to give a near life-like impression. The phantom is a baby doll, chosen for its size and a head, which are anatomically correct as available. The hand piece is a copy of the ultrasound probe in its real size. This probe is used for navigating along the phantom. An optical tracking system (A.R.T.) is used to detect the position and orientation of the phantom and the hand piece independently from each other. The field of view of the tracking system limits the area where the phantom and the hand piece can be used.

The computer used for this system, is a standard PC with Intel® Core™ 2 CPU (2,13GHz), 2,00 GB of RAM and a NVIDIA GeForce 8800 GTX graphics board. Windows XP Professional, Version 2002, SP 2 is used as the operating system on this machine.
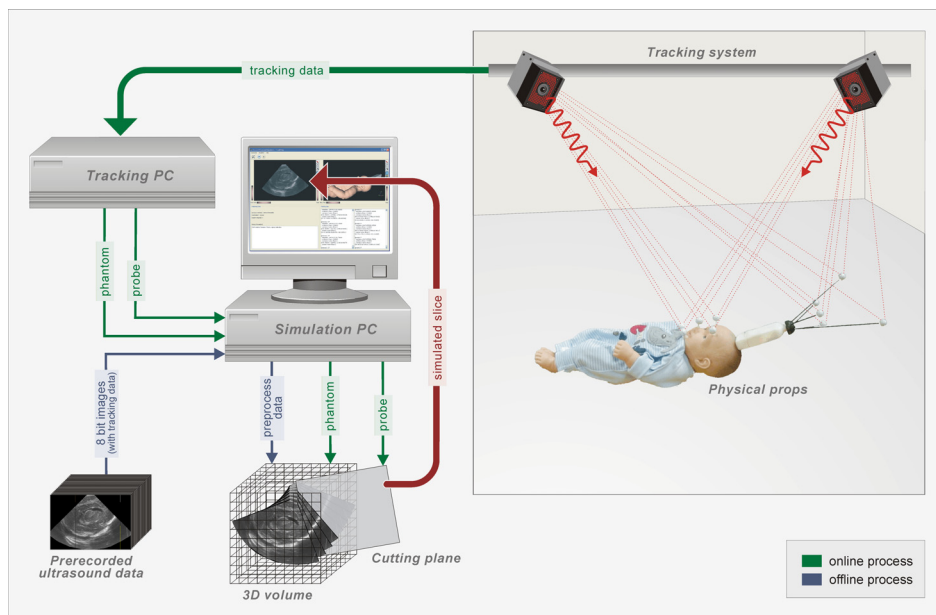

Figure 2: The system components of CranUS

The phantom and the hand piece have a realistic representation as virtual 3D objects in the virtual part of the simulation. The information, obtained from the tracking system, is used to position these virtual elements. The computer gets a prerecorded set of sonographical images from a real patient. In an offline preprocessing, these images are used to generate a 3D volume. This volume is positioned by the tracking data of the phantom, augmenting the phantom with a virtual representation of a brain volume. The tracking information from the hand piece, is used to place a cutting through the 3D volume. This slice is displayed as the resulting sonographic image on the computer screen. The core part of the simulation is to display the slice according to the positions of the phantom and the hand piece.

Compared to *CranUS*, the approach of Maurer et al. [2] is focused to a visual augmentation of a head phantom. There is no further interaction with the phantom involved. Simulating a real neonatal cranial sonograhy, *CranUS* uses no HMD. The approach by Hinckley et al. [3] trains slicing trough the head like *CranUS* does. But its sizing is far from reality, and no training in using the handheld probe the right way s indented. The full virtual approach by Berlage et al. [6] and the patient simulating approach by Ngo et al. [7] are two extremes of a range, where *CranUS* is positioned in between. It uses real sonographic images as a raw material, augmented in to a virtual volume, but still providing touchable phantoms for handling practice. Similar to the setup of *CranUS* the needle guiding system of Magee et al. [8] is using a phantom and an ultrasound prop. Different to *CranUS*, sonography is used only to control the position of the needle prop as the main training instrument.

The approach of *"UltraSim"* by Aiger and Cohen-Or [9] is the one, most similar to *CranUs*, in its focus on training sonography. *CranUs* is designed to teach a special examination task, using a newborn phantom and a mockup ultrasound probe, the cranial ultrasound examination of a newborn using the anterior fontanelle.

Because of the nature of this subject, the sensitivity of a newborn, especially its head and the area of the fontanelle, there are special considerations to be taken. For example, *CranUs* will constantly track possible movements of the phantom itself. Using a standard PC for calculating and displaying the images involves moderate costs compare to a real ultrasound device. In its current state, *CranUS* is not a commercial product, but designed for educational purposes.

Registration of the Ultrasound Volume

The registration of the ultrasound volume is needed for virtually placing it inside the head of the phantom, under the anterior fontanelle. Because there was no appropriate information about the movement of the patient during the prerecording scan, this registration is inevitable. Tracking information from the patient during a scan, would allow an automatically regsitration of volume towards in the phantom. To compensate the lack of tracking information from the patient, it is required to registered the 3D volume manually (*Figure 3*).

CranUS places the 3D volume underneath the anterior fontanelle (origin of the phantom prop). No additional rotation or loaction information is given. An experienced radiologist is needed to adjust its position and orientation correctly in the head of the phantom. Moving or rotating the 3D volume to a position that matches the actual position of the hand piece prop, the registration is done.
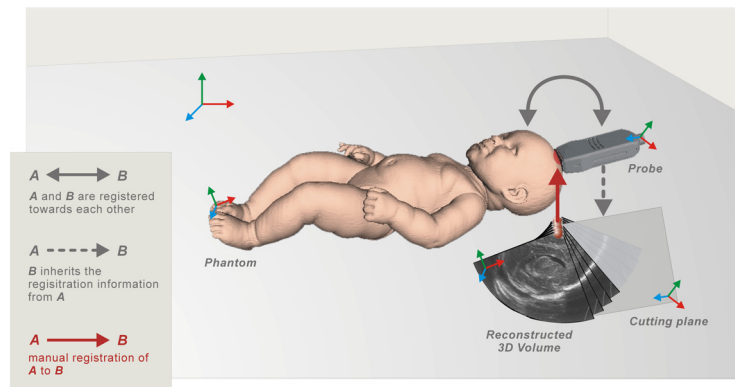

Figure 3: The concept of inherit registration by tracking patient and probe

During this process, both props, hand piece and phantom, are tracked. The movements of the volume are performed with a predefined key set on the computer keyboard. The registration of a volume is needed only once. After saving the registration information, the volume is simply loaded into the phantom.

Data Acquistion

The major disadvantages of the predetermined prerecording process is the fact that no movement of the patient is recorded. To present the position and orientation of the slices towards each other, a tracking path of the probe is shown. The tracking path is mapped along a row of points, where each point represents the position and orientation of the real ultrasound probe for a particular slice during the prerecording scan.

Displaying the position and orientation of the ultrasound images, results in a fan shaped array of planes (*Figure 4*). Regarding any positioning information of the probe, is based on the assumption, that an experienced radiologist compensates for most of the patients movement by movements of the probe (*Figure 4b*).
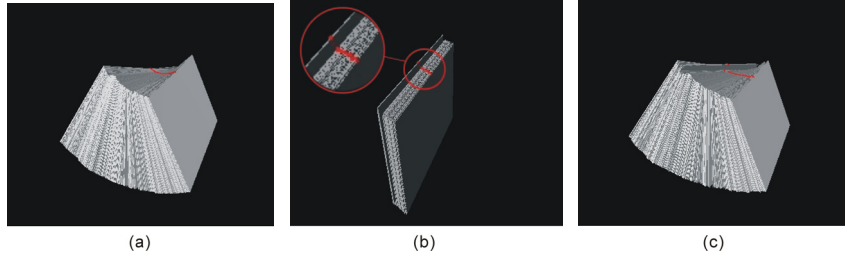
Figure 4: The trackingpath displaying the orientation (a), only the position (b) and both, orientation and position (c), of the real ultrasound probe and the corresponding slices

The inaccuracy in the prerecording process prevents a correct mathematical description of the real tracking path related to the baby's brain. Compensating the movement of the patient with statistical mathematical operations seems to be ambitious, because of the lack of reasonable boundary values.

Has such an inaccurate positioning any value for the later construction of the volume? The only likely solution is to ask the expertise of a radiologist to interpret the real tracking path and the generated volume. A review of the real tracking path allows estimating the likelihood of a realistic volume.

Volume Reconstruction

A rich dataset of prerecorded images can contain more than 400 images. These images are positioned in a joint coordinate system by considering the orientation information during their recording. The result is a fan shaped sweep of pictures.

To describe an area, where the volume is placed and its computation is performed, a bounding box is created. The bounding box is intended to describe the border of the volume as close as possible in an orthogonal manner.

The pictures of one dataset, delivered from the prerecording, are all equal in size (*width*height*). In a first step the vertices p_0, p_1, p_2 and p_3 of one image are calculated (*Figure 5a*):

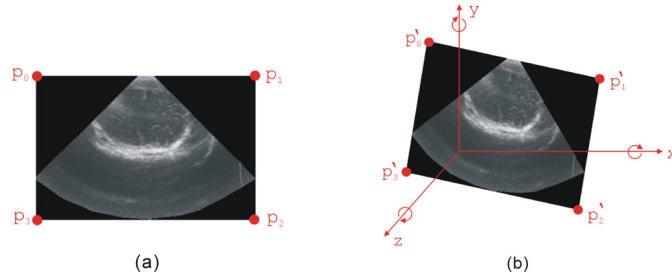$$p_0 = (0,0); \; p_1 = (width, 0); \; p_2 = (width, height); \; p_3 = (0, height)$$

Figure 5: Volume Reconstruction; (a): vertices of a prerecorded image; (b): transformed vertices of a prerecorded image

The two-dimensional coodinate system is now enhanced with a third coodinate z. These enhanced vertices p'_0, p'_1, p'_2 and p'_3 are now transformed with the transformation matrix T from the position and orientation information of the original image (*Figure 5b*). The transformation describes a new position for the points v_0, v_1, v_2 and v_3 in the three-dimensional coodinate system, which maps to the corresponding orientation of the ultrasound probe.

$$p'(x_i, y_j, z_0) = p(x_i, y_j, 0), \; where \; i = [0, width-1], \; j = [0, height-1]$$

$$v_0(x,y,z) = T * p'_0(x,y,z_0)$$
$$v_1(x,y,z) = T * p'_1(x,y,z_0)$$
$$v_2(x,y,z) = T * p'_2(x,y,z_0)$$
$$v_3(x,y,z) = T * p'_3(x,y,z_0)$$

This transformation is performed for every image of the dataset. During this operation, the absolute minimum value for each vertice x_{min}, y_{min} and z_{min} of every coordinate is calculated and stored. The same operation is done for the corresponding maximal value x_{max}, y_{max} and z_{max}.

$$x_{min} = min(\ v_0(x),\ v_1(x),\ v_2(x),\ v_3(x)\ ), \quad x_{max} = max(\ v_0(x),\ v_1(x),\ v_2(x),\ v_3(x)\ )$$
$$y_{min} = min(\ v_0(y),\ v_1(y),\ v_2(y),\ v_3(y)\ ), \quad y_{max} = max(\ v_0(y),\ v_1(y),\ v_2(y),\ v_3(y)\ )$$
$$z_{min} = min(\ v_0(z),\ v_1(z),\ v_2(z),\ v_3(z)\ ), \quad z_{max} = max(\ v_0(z),\ v_1(z),\ v_2(z),\ v_3(z)\ )$$

The distance x_{dim}, y_{dim} and z_{dim} between the minimum and the maximum value for each coordinate is now calculated:

$$x_{dim} = abs(x_{min} - x_{max})$$
$$y_{dim} = abs(y_{min} - y_{max})$$
$$z_{dim} = abs(z_{min} - z_{max})$$

The resulting distances are used as the dimension for the voxel space $V(x, y, z)$, where all images of one dataset are will be mapped. This mapping is done in a similar procedure as before, except that now not only the vertices, but all pixels of each image $I(x,y)$ are calculated:

$$V(x, y, z) = T^R_i * I_i(x,y,0)\ ;\ i = [0, n-1]\ \text{where n is the number of images in a dataset}$$

A voxel, that has now a corresponding pixel is mapped with its grey value c, one out of 256 (8 bit):

$$c_{v(x,y,z)} = c_{p(x,y)}\ ;\ v \in V,\ p \in I$$

The alignment of the images from the prerecorded dataset, does not fit into a regular grid. Therefore either overlapping or gaps with no pixel result.
In the case of more than one pixel falling onto one voxel an arithmetic mean is calculated. The resulting average value c' is used for that particular voxel.

$$c' = (c_1 + c_2 + \ldots + c_n)\ /\ n$$

The resulting fan shaped array of images, displays all parts of the volume originating from the ultrasound scan. The angles in between the volume are around 45° in each direction. The resulting volume still has overlap and gaps, that need to be considered.
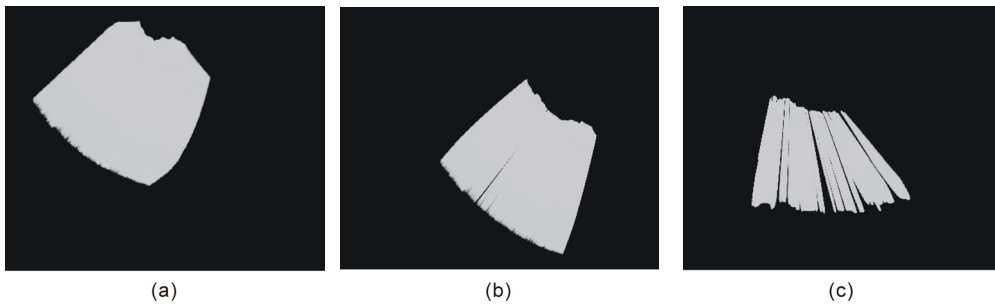

(a)   (b)   (c)

Figure 6: The reconstruction volume with only the rotation information.
(a) and (b): 405 slices; (c): same volume with only 199 slices

The scan used as a test volume consists of 405 slices in the sagittal direction. To get such a rich scan with narrow angles needs an experience handling of the probe. A scan with such narrow angles has less gaps, then scans with a lower number of images. The side view of such a volume shows that there are some gaps left. To construct a volume, which allows slices differing from the original

ones, calculation of the overlapping and additional interpolation of the gaps is needed. The overlapping was already considered during the construction of the volume by arithmetic mean.

Interpolation of the Ultrasound Volume

Slicing through the rendered volume can lead to incomplete pictures (*Figure 7*), showing slices in a tilted plane, slicing through multiple original images.
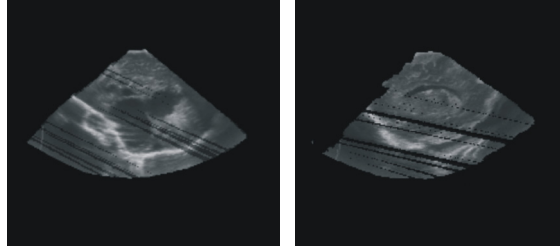

Figure 7: Different slices through the reconstructed test volume

Filling the gaps in between the original images, is done by interpolation. To get an appropriate interpolation result, a proprietary multi-stage interpolation procedure was developed. During the reconstruction of the 3D volume, a distance weighted interpolation is done between two neighbouring ultrasound images. After the reconstruction, a second interpolation is done through the volume, using a nearest neighbour algorithm.

The distance weighted algorithm is performed between two planes, each containing an original ultrasound image. For each pixel p_k of an image I, the location information is used to chose the corresponding pixel from its neighbouring image. Using the tracking transfomation T_i and T_{i+1}, the position of both voxels v_a and v_b in the voxel space V is used for a linear interpolation of the voxels between v_a and v_b:

$$v_a = p_k * T_i \quad \text{with } p_k (x,y,0) \in I_i$$
$$v_b = p_k * T_{i+1} \quad \text{with } p_k (x,y,0) \in I_{i+1}$$

for $k \in [0, l]$ with $l = width * height$ of one ultrasound image and $i \in [0, n]$ with n number of images.

The distance d between v_a and v_b is calculated and used to scale the number of interpolation steps. Along this line, the voxels are interpolated:

$$d = |v_a - v_b|$$
$$v_{new} = v_a + (1/d) * (v_b - v_a)$$

The grey value c_{new} of each interpolated voxels v_{new} is calculated, based on the grey value (c_a, c_b) of v_a and v_b, weighted with its distance to each side dv_a and dv_b.

$$dv_a = |v_a - v_{new}|$$
$$dv_b = |v_2 - v_{new}|$$
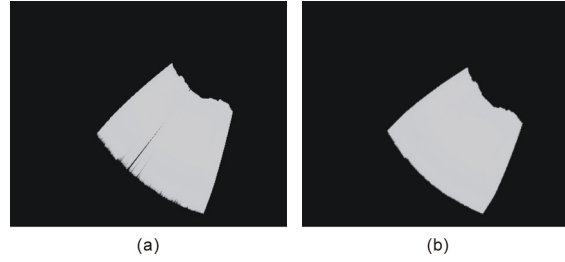$$c_{new} = (dv_b / dv_a + dv_b) * c_a + (dv_a / dv_a + dv_b) * c_b$$

Figure 8: The rendered test volume; (a): without Interpolation; (b): with distance weighted interpolation

After the distance weighted interpolation nearly all gaps are now closed (*Figure 8*). The same slice through the test volume before and after the interpolation is seen in *Figure 9a, b*. Another image is showing another slice with interpolation, displaying some scatters left (*Figure 9c*).
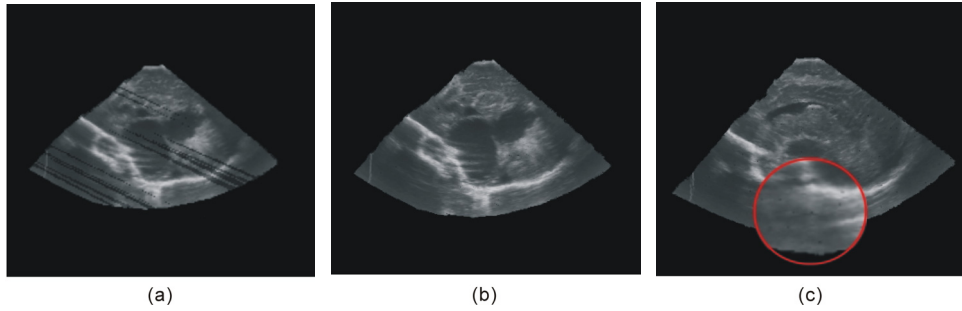

Figure 9: Slice through the test volume; (a): without interpolation; (b) and (c) with distance weighted interpolation

To fill the small spots, left after the distance weighted interpolation, a nearest neighbour interpolation is performed, using a 26-neighbourhood. The 26-neighbourhood considers every neighboring voxel, bordering the voxel to calculate.

For each voxel, that has no grey value at this stage, the nearest neighbour interpolation is done by setting the grey value c_{new} of the voxel in question to the arithmetic mean of all neighbouring voxels n, which already have a grey value c_i:

$$c_{new} = (c_0 + c_2 + ... + c_n) / n$$

The final result of the multiple staged interpolation (*Figure 10*), will be displayed as an output on the *CranUS* interface. → Das Verfahren entspricht doch einem Paper aus dem Related Work, oder? Dann sollte irgendwo ein Satz hin, „similar to xxx's approach".
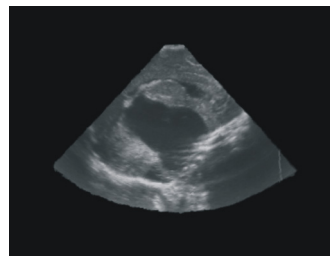

Figure 10: Slice through the interpolated test volume, using distance weighted and the nearest neighbour interpolation

User Interfaces

The ***physical user interface*** of *CranUS* has two main elements, the phantom and the hand piece (*Figure 11*). The phantom is in general a baby doll, chosen for its most life-like head. Mounted on the surface of the doll's head are five passive tracking markers for optical tracking. The tracking markers are mounted in a non coplanar manner. At least four tracking markers would be needed to achieve tracking in 6 degrees of freedom (DOF). The hand piece is copy of a sonography probe in plastic material, filled with an amount of metal to make it weight like a real probe. At the top of the hand piece, a full tracking tree with five passive tracking markers, is mounted.

Figure 11: The physical user interface (PUI) of CranUS

The ***graphical user interface*** of *CranUS* consists of three components. Two components are used for the offline preparation of simulation elements as creating the volume and the manual registration of the reconstructed volume towards the prop. The online mode displays the received and computed information from the tracking system and the resulting slice. This is the main simulation mode used for the training (*Figure 12*). The actual slice through the reconstructed volume is displayed in the upper left quarter. The upper right quarter shows as a reference model, the virtual proxies of the phantom and the probe, positioned in real-time. Additional visualization and tracking information is shown in the other parts of the screen.
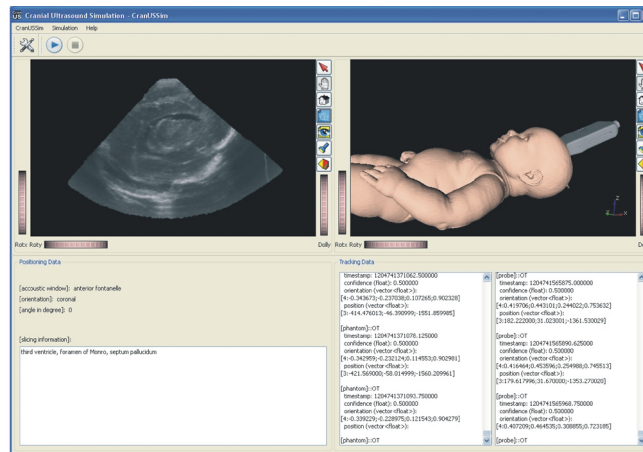

Figure 13: The simulation mode of the graphical user interface (GUI) of CranUS

Evaluation

A user study was carried out to evaluate the usability and the general behaviour of a *CranUS* setup. The opportunity provided by the annual congress of the *European Society of Radiology* [17], the *ECR 2008* (*European Congress of Radiology*) in Vienna, was taken to present *CranUS* and perform a user study.

The main purpose of the study was to aquire information as to how users interact with the system. In particular the handling of the props, as the core part of the simulation, was a part of the evaluation, focusing on the handling of the probe. The quality and usability of the 3D volume and

the interpolation during its reconstruction process was another important factor to look at. A further point of interest was the use of the graphical interface with the visualization of the virtual props as the proxies of the physical props.

To install the system on the *ECR*, a mobile setup was chosen (*Figure 13 left and middle*). It consisted of a mobile version of an optical tracking system from *A.R.T.* consisting of two cameras and a host to process the tracking data and deliver it to a second computer system, where *CranUS* was installed. Real props were used to perform the simulation; their position and orientation was tracked and displayed accordingly on the *CranUS* screen. The setup for the evaluation during the *ECR* was imperfectly calibrated regarding the registration of the 3D volume towards the head of the phantom. It was still sufficient to perform the evaluation task. To achieve a homogeneous test situation, only one virtual test volume, containing a diagnostic finding, was loaded for all tests.

Figure 13: CranUS on the ECR 2008 in Vienna; left and middle: the setup of CranUS; right: a participant guides the probe

Congress participants were asked to perform a neonatal cranial examination within the simulated environment of *CranUS* (*Figure 13 right*). One task was the localization of the anterior fontanelle on the phantom and orienting the probe towards it. By moving or angling the probe, the participant was asked to try to acquire optimal slices as in real sonography. Because of an anomaly presented in the test volume, we also asked the user for any diagnostic findings.

To explore the opinion of the users after a test session on *CranUS,* a questionnaire with four different sections was given. The first section asked about the person and their experience in neonatal cranial sonography. In another section questions were asked about the realism of the props, regarding their handling. The quality of the display concerning the sonogram and the generated slices through the 3D volume is part of another section. The last section was investigating the efficiency, the timing behavior and the training elements, like the reference model, shown in the graphical user interface. To adapt to the conditions during a large congress, the questionnaire was required to be short and easy to fill in.

Evaluation Results

The answers in the questionnaires are illustrated in a bar chart using a Likert scale from one to seven as used in the questionnaire (*Figure 14*). The bar chart does not distinguish between radiologist and other participants, because the answers to some of the questions are not requiring it. Additionally, the mean for every question was calculated.

The age of the test users was between 21 and 60 years, with only one person older than 40 years. Overall, eleven users tested *CranUS* and filled in (an) questionnaire. Two of the participants were female and 9 male. Attendees of a radiology congress can be expected to have an adequate background in radiology overall. Two of the participants were radiologists, one person had rich experience in neonatal cranial sonography. Following these numbers, the focus of the evaluation is on the training functionality and general sonography.

The answers concerning the ***realism*** of the simulation, were neutral or positive with one exception from the experienced radiologist.

Two questions about handling of the probe:

R - Q1: *Were you able to use the probe as expected?*
R - Q2: *Were there any problems in guiding the probe?*

The answers in this area suggest, that handling the probe was not a serious problem with a mean average of *5.909* on *Q1* and *6.545* on *Q2*. There was no significant difference between the radiologists and the other test users.

Three Questions are comparing the simulated situation with the real one:

R - Q3: *Were there differences between the simulation and the real examination situation?*
R - Q4: *Did the displayed sonogram met your expection regarding the positioning of the probe –*
       have you registered any discrepancies?
R - Q5: *How fast was the reaction speed during of the simulation regarding the guiding of the*
       probe and the resulting sonogram?

Relating this simulation with a real neonatal cranial sonography, needs experience in this task. The questions were answered with the following mean averages: $Q3 = 4.14$, $Q4 = 5.555$ and $Q5 = 6.5$. Only one test user had performed such examination before. Considering the audience of a radiology congress, some experience or specialized knowledge about sonography can be expected. Most of the answers are in the better half of the scale, regarding the realism of the simulation.
Comments on question *Q3* were made, missing the presence of gel and claiming some divergencies in display. The latter could be explained with the insufficient calibration of the prototype setup.

R - Q6: *How difficult was the task of localizing the anterior fontanelle and retain it?*

This question was answered with an average of *5.7* on a scale from 1=*hard* via 4=*moderate* to 7=*easy*.

Regarding the ***quality of display***, four questions were asked. The calculated average was always in the better half of the respective scale.

Questions about the expectation:

D - Q1: *Were the sonograms as expected?*
D - Q2: *Was the signal noise of the sonogram as in a real sonography?*

These answers point to an acceptable image quality of the simulation display of the sonography, with a mean average of *4.54* on *Q1* and *4.889* on *Q2*. An outlier in *Q2* is likely to come from an experienced technician, who knows signal noise of images well.

Questions about incomplete images:

D - Q3: *Have you seen incomplete images?*
D - Q4: *Did some incomplete images where disturbing?*

The answers are showing the interesting effect, that incomplete images were found, but were not disturbing that match. This could be explained by the fact that practical sonography also involves incomplete images and practitioners are used to them. The questions were answered with the mean averages of *5* for both, *Q3* and *Q4*.

To get information about the ***efficiency*** of the system, three questions were given:

E - Q1: *How fast were you getting an optimal slice, relating to a real sonography?*

The answers to this question reveal that this simulation permits easily creating slices through the volume. The mean average of this answers is *6*.

E - Q2: *Have you seen any findings?   If yes - was it difficult to localize?*

The candidates were asked, if they have seen a diagnostic finding. The test volume contains a cyst. Six people were able to localize the finding and one candidate even specified the cyst. The difficulty in localizing the finding appears with a mean average of *5,5*.

E - Q3: *Was the reference model supportive for acquiring the right slicing positions?*

An interesting structure of the answers is seen in the last question. Most of the candidates, with a mean average of *5.75*, were using the reference model as support. It is interesting to see two people were not using the reference model at all. The questionnaires reveal that these answers were coming from candidates, experienced in sonograpic technology. Real sonography does not have a reference model. Practitioners are used to evaluating the slices directly. The other answers show that a reference model can be supportive.
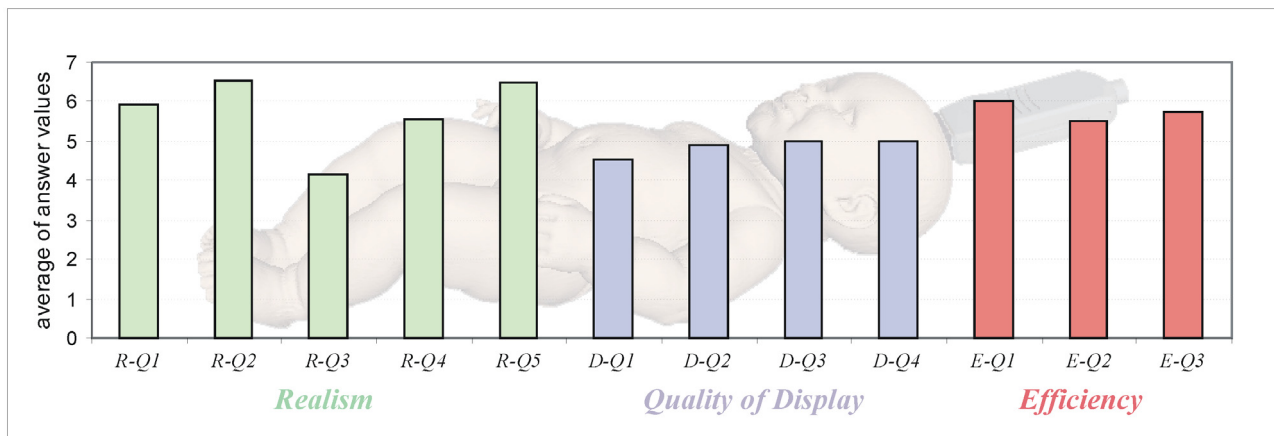

Figure 14: Average results of CranUS evaluation

Comprehensive Survey

The low number of test persons affects the ability for statistical analysis, but the choice of the audience (visitors at *ECR*) adds value to information achieved with the tests. The overall assessment of the answers given is that most of them were in the better half of the scale offered for answering. The setup used for the test was a prototype setup with insufficient calbration, but all test subjects were able to perform the test. As *CranUS* is intended for teaching and training, it was valuable to have several participants without previous experience in neonatal cranial sonography. The evaluation of the questionnaires gives the impression, that the system was accepted and reasonable to handle. The reconstructed volume, used during these tests, was well suited for the tasks to do. It could be seen that less experience participants were using the virtual props in the reference frame for navigating to acquire the right slices.

Conclusion and Future Work

The main goal was to create and document the development of an augmented reality system for the purpose of neonatal cranial sonography training. This work was triggered by a request from the Department of Radiology of the Medical University of Graz (MUG). It was important to have a running system capable of performing the given task. Starting with a physical representation of the child as a baby doll and a physical copy of an ultrasound probe, the system was designed to track the movement of both props and to augment the head of the baby doll with a virtual representation

of a prescanned brain. This was done by modeling each prop into a virtual representation and correlating their movements with one another and to add the 3D volume as an augmentation into the scene. The result of the implementation was a working prototype of *CranUS*, the neonatal cranial sonography simulator. This prototype in a mobile version was presented at the *European Congress of Radiology 2008* (*ECR*) in Vienna. The opportunity of the *ECR* was used to test the system with a number of different users and to evaluate their impressions and experiences. The evaluation results show the simulator was accepted well and excellently fulfills its design intentions and demands.

Multiple options were seen or suggested to enhance the system to make it more life-like or effective in various ways. Tracking the patient during the process of prerecording images could lead to better 3D volumes and the automatic registration towards the probe. A image to image correlation would open another way of registering prescans from different sources for the creation of 3D volume. It is suspected, that a 3D volume considering typical sonographical imaging errors as signal noise or artifacts would have a better teaching and training effect. This could be evaluated with multiple enhanced 3D volumes and different groups of participants, like radiologists, radiology technicans and untrained, unexperienced persons. A major enhancement of the teaching and training functionality would be the introduction of multiple training tasks. In the actual stage, only an exploring mode is realised. Additional modi can be imagined like finding predefined optimal slices, or finding optimal slice in a certain time. Teaching diagnosis can be done by using 3D volumes with certain diagnostical findings. Varying the phantom is another option of enhancing *CranUS*. Different sizes of the phantom can be used as well as phantoms with randomly provoked movement to train the students abilty to adapt to it. Provoding an phantom with softer head would allow to sense pressure on the fontanelle and signaling it. As requested from a test participant, adding gel between the probe and the phantom, like in real sonography, and considering its effects on the imaging process can enhance the teaching and training effect of *CranUS*. This can be verified in an evaluation as described above. Using a reference model during a training session is suspected to be helpful and supported for unexperienced, untrained students. Training seperate groups with and without a reference model would allow tests, how fast and accurate the optimal slices can be acquired. Varying this approach, an interesting question would be to evaluate the influence of computer gaming or computer use as a modern cultural skills on the benefit of a reference model for teaching and training.

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