A Cost Effective Simulator for Education of Ultrasound Image Interpretation and Probe Manipulation

S.A. NICOLAU,1 A. VEMURI, H.S. WU, M.H. HUANG, Y. HO, A. CHARNOZ, A. HOSTETTLER, C. FOREST, L. SOLER and J. MARESCAUX

IRCAD Taiwan, Medical Imaging Team, 1-6 Lugong Road, Lukang 505 TAIWAN
IRCAD Strasbourg, 1 place de l’hôpital 67091 Strasbourg FRANCE

Abstract. Ultrasonography is the lowest cost no risk medical imaging technique. However, reading an ultrasonographic (US) image as well as performing a good US probe positioning remain difficult tasks. Education in this domain is today performed on patients, thus limiting it to the most common cases. In this paper, we present a cost effective simulator that allows US image practice and realistic probe manipulation from CT data. More precisely, we tackle the issue of providing a realistic interface for the probe manipulation with a basic haptic feedback.

Keywords. Ultrasound image simulation, training simulator, optical tracking

Introduction

Education of young practitioners in most medical specialties, as a first step, is approached using a phantom that simulates the human body. However, most of them are very expensive and provide limited realistic experience to young practitioners. Because of their ease of use and better educative value to young practitioners, software based simulators in medical field have gained more importance in recent years. Indeed, they can reduce the cost and allow education on different kinds of pathology.

Our final goal is to provide a US simulator for education that would allow for practice of US abdominal image interpretation and probe manipulation on patient database. The simulator we propose would offer the following advantages. Firstly, the student could work wherever and whenever he wants without needing to go to the hospital. Secondly, the time spent by a medical expert would be reduced, thus decreasing the education cost. Finally, students could practice on rare pathologies. To provide an efficient simulator for US image interpretation and probe manipulation, there are three major constraints to fulfil: realistic US image simulation, realistic probe interaction and a minimal haptic feedback.

Vidal, Forest, Ni, Blum and Magee propose a US simulator for practicing needle puncture on patient dependent data [12, 5, 10, 2, 9]. The relative localization of the fake US probe is realized either using Omni © Sensable haptic feedback system, an EM tracking system (Ascension ©) or an optical tracking system (ARTrack ©) which makes the system price prohibitive. Cynydd is the only one to propose a cost effective

1 Corresponding Author: stephane.nicolau@ircad.fr
solution to education of US image interpretation [3]. The probe interaction is performed using a wiimote Nintendo © (~30 Euros). However, the system provides no haptic feedback and the probe rotation interaction is limited since the wiimote must be oriented toward the infrared emitter below the visualization screen.

In this paper, we present the development of a low cost simulator for US education devoted to abdomen and that can be used on a standard workstation with a webcam. The principle is to load patient CT data (the skin is automatically segmented), and to move interactively a virtual US probe in the virtual scene on the skin reconstruction. The interaction is realized thanks to a 3D optical tracking of a fake probe that the user holds and moves on the surface of a phantom ensuring a haptic feedback (a cardboard box can also be used). From the position of the virtual US probe on the skin model, we compute the CT slice viewed by the probe. The final corresponding US image is provided thanks to an algorithm that transforms the CT image to US modality (already published in a patent [7]). Although the software part of the project is almost finished, this work is still in progress since we still need to demonstrate the clinical benefit of the system for student education.

1. Methods & Materials

The system is composed of a PC (workstation or laptop) equipped with one webcam. The phantom can be either a basic foam phantom or a simple cardboard box on which several optical markers are stuck (cf. Fig 1). To track the probe and the phantom, we use the ARToolkit+ library [1] to extract the 4 corners pixel coordinates of each individual marker and to identify them. Then, we use openCV library to refine the corner extraction [8]. Each set of 4 corners are then used to compute the marker pose in the camera frame. We print 5 markers that we stick on each face of a plastic cube, which is attached to the fake US probe (cf. Fig 1). Patient data is a CT volume (thickness<5 mm) that comprises the organ of interest. No organ segmentation is necessary, only the skin position has to be identified (using a simple threshold).

![Figure 1. Left: illustration of the equipment to track the fake US probe and the cardboard box. Right: the foam phantom with the definition of the two lines we use to register it in the CT reference frame.](image)

In this section, we firstly detail how we accurately track the US probe using a cube on which 5 markers are stuck. Since this tracking method needs the a priori knowledge of relative positions of each marker on the cube, we then explain how we estimate it with an easy calibration step. Finally, we describe the method that allows tracking the phantom (or cardboard box).
1.1. US Probe Tracking

We firstly calibrate the web camera with the method described in [13], which allows a quick calibration with very few understandings by the end-user. He only has to print a chessboard of markers (for instance 6x5 markers with 3 cm squares) and stick them on a planar surface [4]. The tracking of the fake US probe could be realized in practice using only one marker stuck on it (cf. [1]). However, this approach would limit the possible user interaction since it would prevent the user to make 180° rotation around the probe axis. To overcome this issue, we propose to use a cube with 5 optical markers on its faces. In practice, to know the relative position of all marker corners, we need either to build it, which is expensive, or ask user to calibrate it.

1.2. Calibration of a Cube with 5 Markers on Its Faces

The idea is to move/rotate the cube in front of the calibrated camera so that all possible face pairs are visualized by the camera. Let’s say we want to compute all point coordinates in the frame linked to the top face $F_0$ (cf. left Fig. 2). Using ISPPC [11], each time that $F_0$ is visible together with the $i^{th}$ face $F_i$, we can compute both $T_{\text{cam}-F_0}$ and $T_{\text{cam}-F_i}$. Therefore, for each frame containing $F_0$ and $F_i$, we can obtain one estimation of $T_{F_0-F_i} = T^{-1}_{\text{cam}-F_0} \times T_{\text{cam}-F_i}$. Since we will in practice have several video frame showing at the same time $F_0$ and $F_i$, we will get several estimations of $T_{F_0-F_i}$ that we average to obtain a more accurate estimation (see [6] for more details on averaging rotation). Finally, if we move the cube so that $F_1$, $F_2$, $F_3$ and $F_4$ are one after one visible with $F_0$, we can estimate all point coordinates in the frame of the top face $F_0$.

![Figure 2](image-url)

**Figure 2.** Left: illustration of the frames on the cube. Right: definition of the distance $D$ and $d$ for software.

After the cube calibration, the user has to stick it on his US probe. In order to avoid supplementary calibration step, the user should roughly put the cube on the probe so that the marker centre of $F_0$ belongs to the symmetry plane of the probe (cf. Fig. 2). Then, the user has to measure the length $D$ and $d$ and provide it to the system.

1.3. Phantom Tracking

In case only a cardboard box is available, we propose to stick on one side several optical markers printed on the same page (cf. Fig. 1). The idea is that the marker corner coordinates will be chosen so that they correspond to one side of the CT data volume like depicted in Fig. 3 (left). When the user is moving the probe on the box top side, the probe position is computed and we find the vertex at the same altitude $Z$ which is the closest to the probe (cf. right Fig. 3). Then, we display the virtual probe on this skin vertex in the virtual scene (we keep the same orientation). This allows giving the user the feeling that the probe moves on the skin whilst he moves the probe on the box.
Figure 3. Left: the optical markers are stuck on one side of the box. Right: to compute the position of the virtual probe on the skin model, we find the vertex on the skin model which is the closest to the line between the slice center and the probe extreme point. On this example, the virtual probe is displayed on the red vertex.

In case the user has a foam phantom, the user has firstly to stick one marker on the phantom side which is in front of the web camera. Then, we ask the user to move the fake probe on the phantom and to record two specific lines: the cranio-caudal line on the highest phantom crest and the line in an axial plane roughly in the middle of the phantom (cf. Fig. 1). This information allows us to register approximately the phantom in the CT frame: we firstly match the intersection of the two lines with the top face centre of the CT data, the orientation is given by the middle axial line which defines a plane and that we match with the middle axial plane of the CT image.

2. Results

On Fig. 4, one can see the final user interface. On the right and centre windows, the user can see the patient skin model (segmented organs can be visualized, but the system does not depend on it) with the virtual probe. Two different points of view can be provided: the right window shows the original CT image corresponding to the probe position and the left one displays the US image simulated in real time from CT image.

Figure 4. Illustration of the software interface.

To evaluate whether a practitioner could use the simulator by himself, we have written a user’s guide that contains guidelines for each calibration steps: webcam, cube marker, cardboard and phantom. Then, we asked 10 residents to read it and perform each calibration. We provided them a cube, a fake probe, a cardboard and a phantom. For each calibration, we have recorded the reading and manipulation duration. They also filled a questionnaire to give a score between 0 and 5 for each step (5 = very easy,
We also asked them whether they consider the system realistic enough (US image and probe interaction: 5 = realistic, 3 = enough realism, 0 = not realistic). Results in Tab. 1 show that the simulator is easy to calibrate and that the realism of simulated US image has to be improved whereas the interaction is good.

Table 1. Evaluation results of our simulator by ten novice users.

<table>
<thead>
<tr>
<th>Calibration step</th>
<th>webcam</th>
<th>cube marker</th>
<th>box</th>
<th>phantom</th>
<th>US image</th>
<th>interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average score (0 to 5)</td>
<td>4.6</td>
<td>4.1</td>
<td>4.4</td>
<td>4.2</td>
<td>2.8</td>
<td>4.4</td>
</tr>
<tr>
<td>Average time (sec.)</td>
<td>304</td>
<td>332</td>
<td>155</td>
<td>225</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

3. Conclusions

We have presented a simulator for education of young practitioner to US image interpretation and probe manipulation. Our objective is to provide a cost effective simulator that allows basic haptic feedback and which can be easily used with a standard workstation. In this paper, we have showed how we reach our aim using a simple webcam and several planar optical markers printed on paper sheets.

More precisely, we have firstly explained how it is possible to robustly track a fake probe using a web camera. Secondly, we have described simple methods to use a phantom or a box to mimic the patient position. Finally, an evaluation with ten novice users showed that the simulator is easy to calibrate and that the system realism is encouraging. However, some efforts still have to be spent on US image simulation. Our next step will be to improve the US image simulation following expert remarks and evaluate the simulator benefit for education of young residents.

References