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Chapter 21

Virtual Echography

The Simulation of Ultrasonographic Examination

Delphine Henry,[1] Jocelyne Troccaz,[1] and Jean-Luc Bosson[2]

[1]Laboratoire TIMC–IMAG, Faculté de Médecine—IAB, 38700 La Tronche, France (Delphine.Henry@imag.fr)
[2]Service d'Angiologie, CHU A. Michallon, 3800 Grenoble, France

Abstract:

We present a Virtual Echographic System. Because this examination is particulary difficult, developping a simulator is very useful to give students some common databases of pathological samples on which they could experiment image acquisition and evaluate their understanding of clinical cases. We have applied our method to the simulation of thigh ultrasonographic examination for thrombosis diagnosis. A preliminary system, focusing on image generation, has been developped. Virtual echographic slices are generated using a particular interpolation technique and a deformation model of significant structures. Resulting images have a visual quality similar to usual ones.

1 INTRODUCTION

Echography has become the preferred mean of diagnosis in numerous pathologies. This comes from its simplicity, low cost, and non invasiveness. However, compared to conventional radiology, it does not permit later rereading. Diagnosis from echographic images is difficult because images are of poor quality. Part of the image understanding comes from the dynamic aspect of the acquisition. The dynamic aspect is important both in terms of probe position and anatomical structure reaction. Anatomical structure reaction results from the pressure exerted by the probe over the body. Regarding diagnosis of thrombosis, it is generally considered that the number of necessary examinations before having a good technical competence is around 1000. The first 500 examinations made by a student must then be re-checked by a senior physician. The possibility of virtual echography, providing intensive training, would be a very important jump and would allow more time for clinical training of students. Thus, they could train themselves to acquire images and evaluate their understanding of clinical cases. The virtual echography would allow an increase in the extensive training skills including rare cases, independently of the number of patients of a given medical department. Besides, such a virtual echographic system could speed up new treatment evaluation since it would allow to establish evaluation standards.

2 SCIENTIFIC OBJECTIVE

The major scientific objective is the development of simulators to improve diagnosis and to rationalize evaluation [1]. We intend to develop a final system based on the following concept. When a pathology of particular interest presents, an experienced radiologist performs an echographic examination on the patient containing all the information necessary for a correct diagnosis (in our case: images of the vein with different significant levels of pressure). Then, any new operator can use a virtual echographic probe to perform a simulated acquisition and diagnosis based on the collected data. He will see the corresponding images and feel the contact with the virtual patient in real-time. This implies the ability to model the relevant structures in terms of shape and reaction to an external force in order to realistically reproduce the information that the physician perceives during his examination.

3 MEDICAL CONTEXT

A specific application dedicated to the diagnosis of deep venous thrombosis of the lower limb [3] is carried out in collaboration with the Angiology Department of the Grenoble University Hospital. Such pathology can be detected analysing the vein collapsing when applying pressure on the thigh with the echographic probe. *Figure 1* sketches out different echographic images that would be obtained by applying increasing pressure. *Figure 1.a* symbolizes the initial situation where there is no exerted pressure. As the pressure increases, the vein becomes progressively flat (*see Figure 1.b*). When probe pressure is greater than veinal blood pressure, the vein collapses (*see Figure 1.c*). If probe pressure goes over arterial pressure, the artery pulsates (*see Figure 1*.d). Vein incompressibility, detected from the image deformation, is the pathological sign of a thrombosis. In a pathological case, the image would remain in the *Figure 1.b* state.

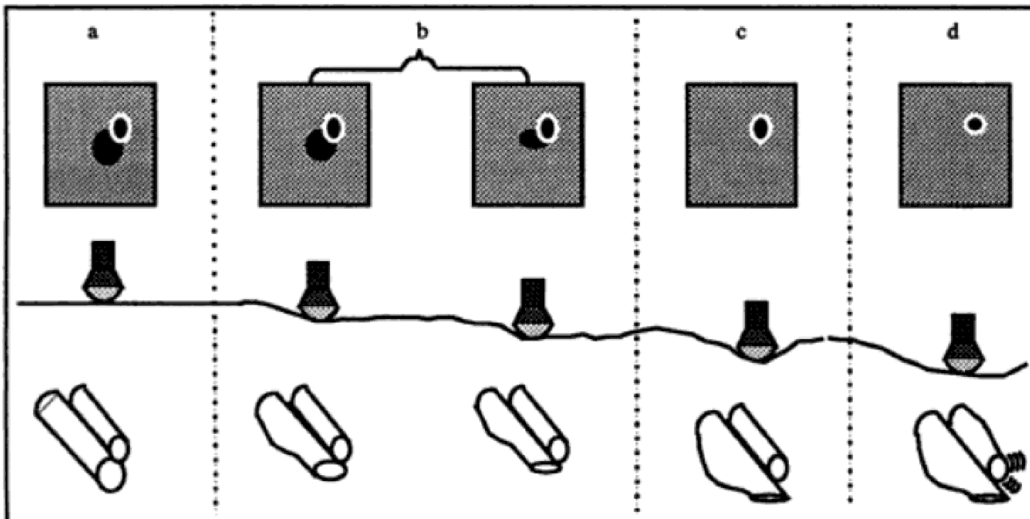


Figure 1 - *Echographic aspect of a non pathological vein* -

4 TECHNICAL APPROACH

Developping such a system sets several problems: locating echographic data in space, segmenting images, modeling anatomical structure deformations or integrating virtual reality technologies.

A preliminary system, focusing on image generation has been developped. Virtual echographic slices are generated using a particular interpolation technique and a deformation model of significant structures. The steps needed to construct an ultrasound image are described in *Section 4.1 and Section 4.2. Section 4.3* presents the system of force feedback which will be necessary in the final system to give back a realistic tactile feeling.

4.1 Database construction

a. Ultrasound acquisition

Images are gathered from a real echographic acquisition. Using a 3D localizer, images are located in space. In fact we use infrared tracking of the ultrasound probe. Infrared diodes, put on the probe, are located thanks to an optical localizer (Optotrak Northern Digital Inc.). To be able to relate Reftrack to Refimage (*see figure 2*), the echographic probe has to be calibrated [3]. This calibration requires the determination of two transformations : from Ref*image* to Ref*probe* (intrinsic calibration), and from Ref*probe* to Ref*track* (extrinsic calibration). Intrinsic calibration determines two linear scaling factors by means of a calibration object, while extrinsic calibration is based on 3D point matching. Using this system echographic plane position and orientation, stored in a location matrix, can be acquired simultaneously to the image.

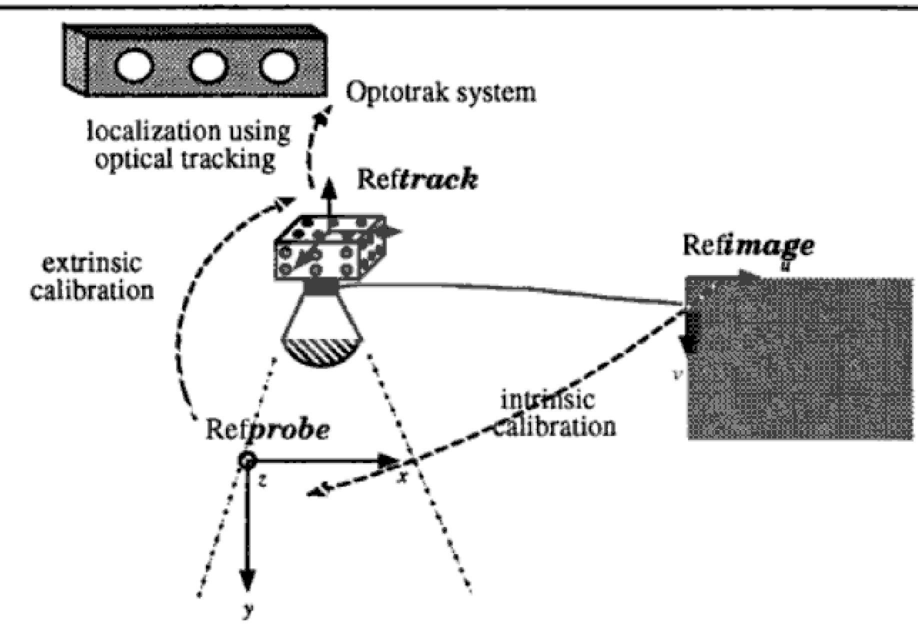


Figure 2 - *image 3D localization* -

In the case of thrombosis diagnosis simulation, we use this ultrasound imaging system. Images are acquired, with minimum probe pressure, all along a "real patient" thigh (*see figure 3*). Each slice is stored with its location matrix.

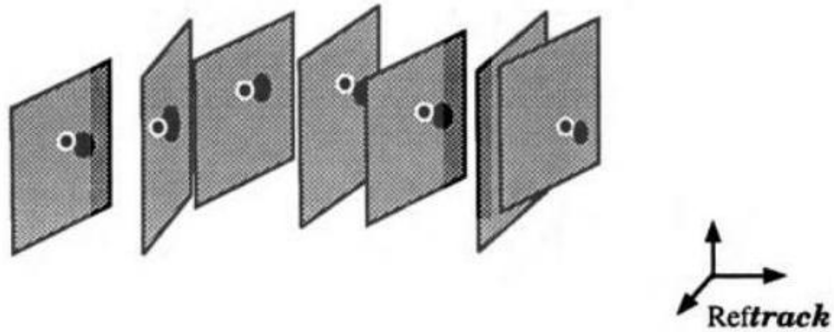
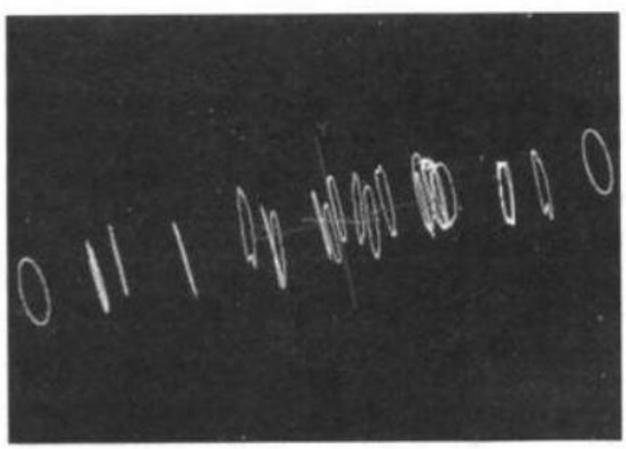


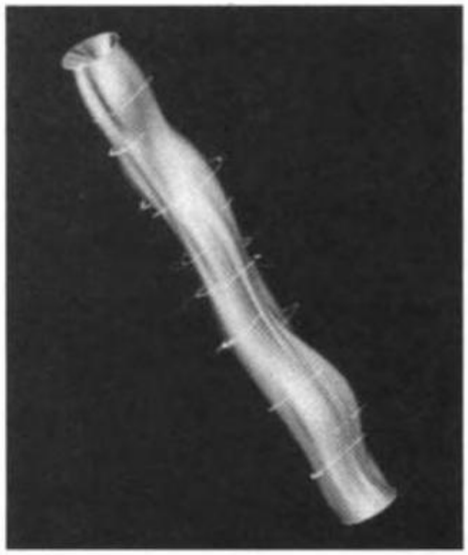
Figure 3 - *Set of echographic slices located in 3D space* -

b. Surface reconstruction

In order to model precisely relevant structures, images are segmented (*see figure 4.a*) and 3D surface model of the structures are generated using a spline representation. In our case we reconstruct the vein and the artery surfaces (*see figure 4.b*).



a - *Segmentation of vein contours* -



b - *Vein Surface* -

Figure 4 - *Vein Surface Reconstruction* -

c. Surface acquisition

To be able to model the contact between the probe and the patient, a necessary step consists in acquiring the skin surface of the patient over the region of interest. This can be done using range finders [4] such as laser based systems or frame projection systems [5].

d. Modeling of anatomical structure deformation

It is also necessary to model the deformation and the displacement of anatomical structures due to the manual pressure imposed by the acquisition. Modeling of anatomical sructure deformations consists in finding a mathematical model in order to calculate the deformations due to a given pressure. In the thigh application, there are three main structures : soft tissues, arteries and veins. Each behavior has to be modeled. Soft tissues flatten out when applying pressure. Their deformation is almost linear. Arteries, due to the arterial pressure, are not deformable except for very high pressure for wich the diagnosis is not possible. For veins, the transformation is based on an elliptical deformation. Two cases have to be distinguished : total collapsing for non pathological veins and less significant deformation in thrombosis cases.

4.2 Image generation

Once the database has been constructed, the simulation satge can be envisaged. For a given position of the probe, the intersection of the echographic plane with the model of relevant structures is computed. In our interpolation scheme, the image, with no pressure consideration, is generated from actual recorded image of the neighbourhood. Then, the image integrates the deformation of structures corresponding to the pressure of the probe over the body. The parts of the image corresponding to structures of interest are computed from the model of deformation. This image generation must be fast enough to be realistic.

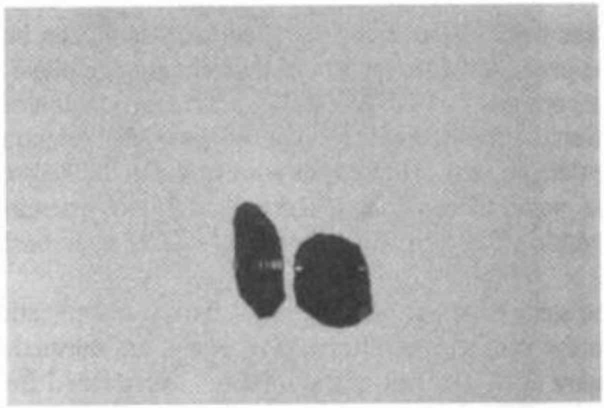
Figure 5 presents the steps of image generation for the thigh application. First of all, the intersection between the vein and the artery surfaces and the selected echographic plane is computed (*see figure 5.a*). The rest of the image is interpolated from the two nearest echographic images acquired beforehand (*see figure 5.b*). The interpolation can be an average, a mean depending on distances or a more complex computation [6]. Once this image without pressure has been created, the final image can be computed considering the model of deformations (*see figure 5.c*).

4.3 Force feedback

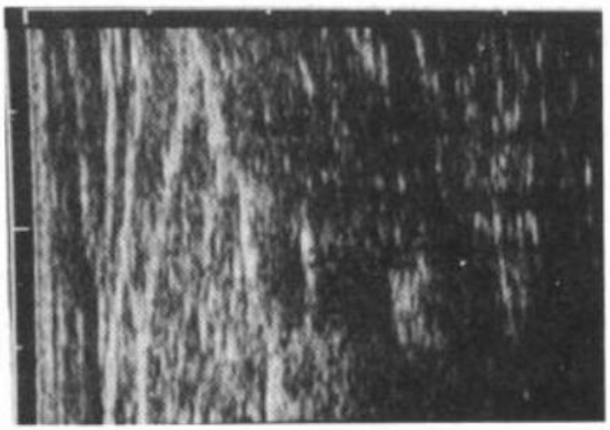
This step necessitate a physical system that gives the operator the realistic feeling of the contact and pressure exerted by the probe on the patient [7]. In the general case, this could be done by using a 6D force feedback actuated mechanism on wich the virtual probe could be installed. Reflecting realistic sensation requires taking into account the type of structures present in the vicinity of the contact region.

5 CONCLUSION

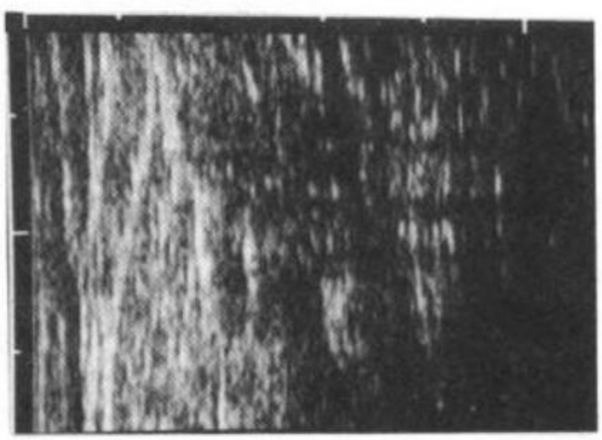
This study has set out the course of the operations in order to elaborate an ultrasound examination simulator. We have illustrated this method using vascular examination of the lower limb. Interpolated images have been computed and compared to actual images: the results are very promising (*see figure 6*). Attention has been paid to image generation but further steps will be necessary to complete the project of a virtual echographic system. Among these steps, we have to take into consideration the physical aspect of the examination. A physical system which gives the operator the realistic feeling of contact and pressure exerted by the probe on the patient has to be elaborated. Another step is the real-time generation of echographic images. Algorithms have to be improved in order to gain computing time. We will also have to generalize our modeling and reconstruction functions in order to address other pathologies elsewhere in the body.



a - *Intersection between anatomical surfaces and the selected echographic plane -*

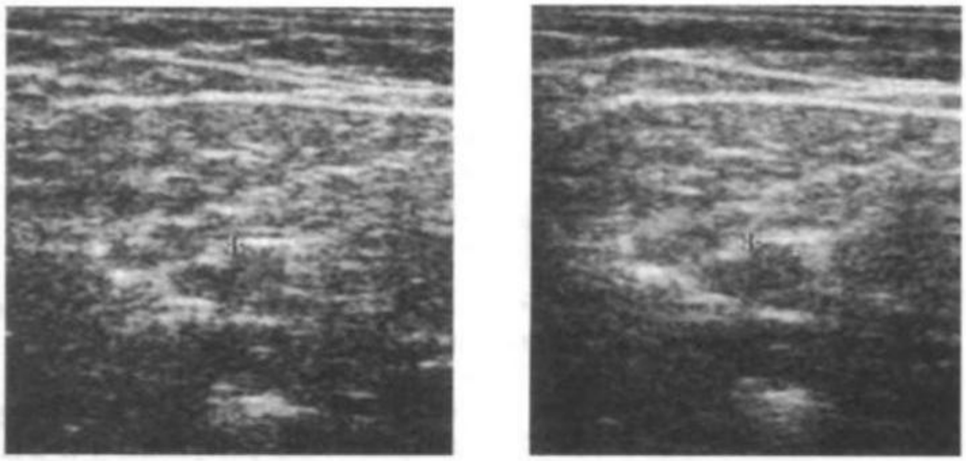


b - *Image generation with no pressure consideration -*



c - *Final image -*

Figure 5 - *Image generation -*



a - *Real ultrasonographic image* - b - *Interpolated image* -

Figure 5 - *Comparison between a real image and an interpolated one* -

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