Learning Ultrasound Gesture Database: Building and Application to Musculoskeletal Ultrasound Exams

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Abstract

Our aim is to develop a frame work for virtually learning the ultrasound exams. In this paper we address the method used to build the image database required for this frame work. The used materiel and the proposed methodology are presented and explained. The realized prototype has been used to build the database of ultrasound images.

I. Introduction

Nowadays, the ultrasound exam becomes largely used due to the technology development. The ultrasound imaging is non-radiating and cheap imaging modality; its advantages allowed it to be used worldwide and to be the first choice for imaging many anatomical structures. Beside these advantages, ultrasound exam is characterized by the difficulty and subjectivity of interpretation. Indeed, the ultrasound image is specified by its specular appearance and doesn't give direct correspondence anatomy, its interpretation is operator-dependent and the presence of the expert is essential to the formation of the learner.

Performing an ultrasound examination involves good hand-eye coordination and the ability to integrate the acquired information over time and space; the physician has to be able to mentally build 3D anatomy from 2D images, gesture information and to put a diagnosis from this information. This is why the training of learners has an important role in the successful practice of their ultrasound exam.

In this paper, we present the material and software tools used for the construction of our database for learning ultrasound gesture. This database is important and constitutes an essential element of the frame work to be developed.

For each position and orientation of the probe, the proposed system allows the acquisition of:

- The force applied by the expert using the ultrasound probe,
- The 3D localization of the probe,
- The associated ultrasound image.

The proposed system is mounted on a free-hand ultrasound probe and is suited for the most complex structures of interest such as the musculoskeletal ones; which are composed of different elasticity structures, bone has a minimum level of elasticity while muscle, tendon, ligament, fats and skin have a high level of elasticity.

In this paper we present the state of the art in section 2. Section 3 is devoted to describe the instrumentation of the ultrasound probe with force sensors. In section 4, we present our study on the acquisition of the elasticity of the targeted anatomy. The acquisition of the ultrasound volume and the reference exam are presented in section 5. Finally, we will conclude in section 6 and present some perspectives and the future work.

II. State-of-the art

Actually, learning is improved by more modern ways based on newest technology development to overcome lacks of traditional learning process. These modern learning ways are based on the simulation of the real learned gesture. Over a complete survey of the existing simulators [1], scientific community is interested by two kinds of simulators for learning ultrasound gesture. Ultrasound simulators with physical plastic model and a false ultrasound probe equipped with a locator which receives the 3D relative position and orientation of the sensor [2, 3, 4, 5, 6]. Virtual simulators are based on biomechanical modeling of the studied anatomical part; this model assumes that the entire region has the same elasticity which is actually heterogeneous, [8, 9, 10]. As far as ultrasound images are concerned, its deformation is not allowed in the existing simulators, only in [8] they deform the ultrasound image linearly which doesn't correspond to the non-linearity deformation of the anatomic structures. Also, the deformation and the haptic rendering are different from real case. It is known that the plastic models have elasticity completely different from that of the human structures. For the virtual simulators the biomechanics models as the mass-spring simulate the non-linearity of the anatomical structure but not the elastic heterogeneity.

To design an optimal simulator, the solution is to acquire the real data and inject them on the simulator. This is done by a robot that holds an ultrasound probe and provides information of the pressure applied through the probe on the patient using force sensors mounted on the hold probe. This can only be achieved using a robotic arm and cannot be achieved manually using freehand [11].

Our contributions in this paper are:

- The proposition of a methodology to acquire the ultrasound image, the probe pose and the pressure applied to the examined organ.
- The acquisition of the 3D volume from ultrasound images.
- An ultrasound reference exam on the studied body part.

III. The Material Solution

Our aim is to propose a solution which provides in the same time:

- The pose of the probe for each reference ultrasound image.
- The construction of the elasticity map.
- The identification and storage of reference the ultrasound images.
- The reconstruction of ultrasound volume of the studied organ.

A. Localization

It is important to have precisely the information of localization for each ultrasound image in world coordinate system. Therefore, the 3D localization and orientation of the probe is acquired using an *NDI Spectra® Polaris* localizer. We equipped the ultrasound probe with a rigid body visible by the camera as illustrated by Fig. 1. This optical localizer gives us the position of the rigid body in the world coordinates system. We calculate the pose of the probe considering the known position of the attached rigid object with respect to the probe.

Before the use of the proposed instrumentation, the 3D localizer must be calibrated in order to compute the 3D position and orientation in the world coordinate system. For that purpose, we have used the calibration procedure developed in our laboratory [14]. This novel concept (patented) for freehand ultrasound calibration method is fully automatic and is based on probe movement simulation in virtual environment.

As for the localizer, the force sensors have to be calibrated before being used, we should know that the maximum force applied in musculoskeletal structures is about 5N. This value was obtained using a scale on which the expert applies with the ultrasound probe the maximum force usually applied on musculoskeletal organs.

The sensors are first saturated with this maximum force value then calibrated by the mean of the calibration tool provided by FlexiForce application [12].

B. The construction of the elasticity map

During ultrasound examination, the practitioner searches to visualize the studied organ by moving the ultrasound probe on the area of interest and applying a force to the organ through the probe until having a useful ultrasound image. Therefore, we are interested in measuring the force applied through the probe when acquiring an ultrasound image. The use of the gel is necessary for the continuity of the ultrasound wave transmission-reception and using it allow to reduce the frictional forces. Due to the fact that the anatomical tissues are isotonic, the range of the reactive force remains the same when the probe orientation varies. Therefore the reacting force has the same amplitude while the applied force is in the opposite direction.

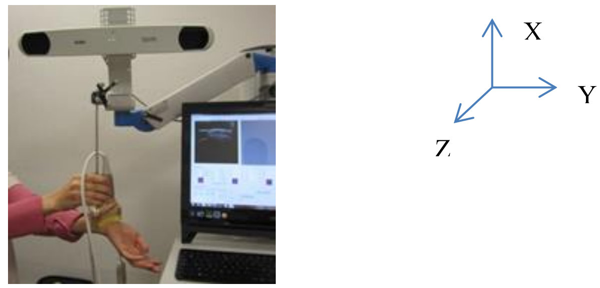

Figure1. The probe instrumented with a rigid body and camera origin system

Force information is feed backed using force sensors wired to a computer via USB connection.

To obtain the force applied through the probe on the structures, we have to use force sensors without altering the ultrasound waves and without disturbing the force acquisition process. The FlexiForce sensors [12] were the most appropriate for our application. This sensor is force sensing resistor and has piezoresistive-effect, it has an accuracy of ±3% and offers the advantage of being very thin, its thickness does not exceed 0.1 mm and with a circular sensitive area which doesn't exceed 0.6 mm of diameter. The ability of this sensor varies from 1 to 100 N. This range is adapted to the variation of force applied through an ultrasound probe to anatomical regions. The minimum force value is applied for articular exams while the maximum value is applied in abdominal exams. We first calibrate the sensors for a maximum value of 5N.

The sensors are placed on the probe so that all the force applied on the probe passes through the sensitive area of the sensor. Therefore, we chose to place two sensors, one on each side of probe opening area without influencing the transmission-reception process of the ultrasound waves. To ensure that all force applied to the ultrasound probe pass through these two sensors, we add two very thin plates with 1mm of thickness and 5mm of diameter, one for each sensor. Our probe has an opening area of 60mm by which the ultrasound waves goes across, by adding the two plates, the opening area remains more than 50mm which is quite enough to have a good ultrasound image, see Fig. 2.

The entire probe, the plates and the sensors are placed in a pocket in Proxon [13]; which is extremely soft polyvinylchloride created especially for the requirements of skin contact sonography. This material exhibits characteristics similar to human tissue in its sonic velocity, sound absorption, and its acoustic wave resistance, it is suited for our case study due to its low sound absorption. The probe protection is made for a linear probe and it is 70mm length and 10mm of thickness. This cover has the same form as the probe and ensures that the force is applied on the entire contact area making the same deformation of the underling tissues as that of the probe. It allows a good ultrasound transmission. We ensure the conductivity of ultrasound waves with ultrasound gel between the probe and the probe cover.

The relative deformation for some points identified by theirs 3D location at different force ranges is illustrated in table 1. It is easy than to recover the intermediate force. The identification and storage of the ultrasound images of reference addition to the force necessary for image production are saved with the relative ultrasound image.

C. The identification and storage of the ultrasound image of reference

A reference exam is considered to be all the ultrasound images that hold pertinent information of the studied organ. For an ultrasound exam, it is important to know where placing the ultrasound probe to begin the exam, this location is different form an organ to another. For each scan, the position and the orientation of the probe in in addition to the force necessary for image production are saved with the relative ultrasound image.

D. The reconstruction of the ultrasound volume of the studied organ

We choose to apply the acquisition schema on the shoulder joint; this structure is a good example of the complexity of the joint and heterogeneity of its structures. These acquisitions are done on healthy man by the expert (clinician).

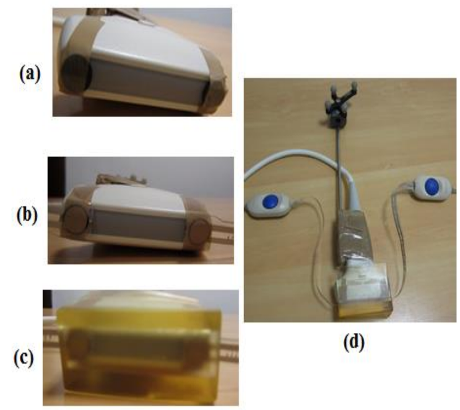

Figure2. (a) Probe instrumented with the plates, (b) Instrumentation supplied with the sensors (c) Instrumentation supplied with the pocket (d) Complete probe instrumented

TABLE 1. TABLE OF 5 SELECTED POINTS DEFORMATION ON SUPRASPINATUS AREA.

Force [N]	***0***				***2***				***4***			
Position [mm e⁻¹]	***X position***	***Y position***	***Z position***	***DX[a]***	***X position***	***Y position***	***Z position***	***DX[a]***	***X position***	***Y position***	***Z position***	***DX[a]***
P1	287.27	178.12	-1153.9	0	301.817	178.46	-1153.8	14,547	362.697	178. 2	-1153.3	60,88
P2	288.39	176.52	-1150.63	0	333.111	176.26	-1150.9	24,713	347.22	176.52	-1150.1	64,109
P3	290.67	174.73	-1039.41	0	299.036	174. 05	-1039.9	8,363	361.903	174. 4	-1039.4	62,867
P4	292.13	172.78	-1143.5	0	256.821	172. 30	-1143.1	8,872	301.008	172. 1	-1143.6	44,187
P5	289.82	170.86	-1174.34	0	255.816	170. 11	-1174.7	12,318	302.061	170. 2	-1174.6	46,245

a: relative deformation on X coordinate.

Once all the sensors are calibrated; the instrumentation is ready to be used. We plan to reconstruct a 3D ultrasound volume of the shoulder using a series of its 2D ultrasound images. The localizer provides the position of every pixel of the ultrasound image; we assimilate the position of the probe to the position of the first pixel of the obtained ultrasound image. To acquire the ultrasound exploration of the studied organ, the expert defines the area of interest; we acquired at each point of the region of interest an ultrasound image and registered the position and force information. The acquisition points are equidistant from each other with a distance of 1mm. This distance was chosen after several tests, it allows us to reconstruct an optimal ultrasound volume. For each force range, an ultrasound volume of the shoulder is associated.

For each point of the area of interest, we get 3 ultrasound cross-sections associated with the force applied to the probe during its acquisition. We obtain an ultrasound volume for each force variation, ultrasound volumes then contain the information on the deformation of the anatomical structures of interest. Fig. 3 illustrates the set of supraspinatus ultrasound images.

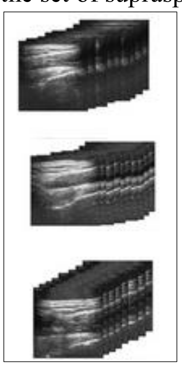

Figure 3. Series of ultrasound images for the global ultrasound volume reconstruction of supraspinatus.

IV. Discussion

The proposed instrumentation is mounted on a free-hand ultrasound probe; it is lightweight and does not affect the ultrasound waves. We insure that the instrumented probe produces a good ultrasound images; the instrumentation is validated by the expert.

The proposed instrumentation is suited for the linear and the curvilinear probe. In this paper we present the adapted instrumentation for linear ultrasound probe because we are interested by the musculoskeletal anatomy; which is our first interest and also for the complexity and the heterogeneity of the anatomical structures composing the body articulations.

The experiments were done using *L12-5L60N TELEMED®* ultrasound probe, which has a range of high level frequencies with an open area of 60mm and is adapted for superficial and musculoskeletal structures.

V. Conclusion and Future works

In this paper a novel method to construct a learning database for ultrasound examination has been presented. This database for ultrasound learning purpose is built so that the learner does not require the presence of the patient or the expert to guide him. We proposed an instrumentation of the probe that allows us to accurately acquire the location information and to measure the force necessary for the formation of the ultrasound image without affecting its quality. Location and force information as well as the associated ultrasound image can be transmitted in real-time via a network; the expert in a remote station can then guide the learner to position the ultrasound probe.

This work is being continued to design and provide an optimal simulator. The aimed simulator is virtual and affordable using the adapted joystick. We plan also to make the procedure of acquisition less expansive by replacing the optical Polaris camera by a Kinect sensor; this would make the final simulator less expensive and permit large utilization of the simulator.

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