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Virtual Navigator 3D Panoramic for Breast Examination

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Abstract— **Breast examination both for screening and second level of investigation has spread worldwide, due to increased breast cancer awareness. Thus, different diagnostic imaging technologies emerged in breast application. Ultrasound (US), a real-time examination, non-invasive, cost effective, ideal also for repetitive follow-up and able to give information about anatomy, hemodynamics and tissue stiffness, plays an important role in breast diagnostics. The present work describes the innovative three-dimensional (3D) Panoramic (Pan) tool of Virtual Navigator technology for real-time fusion imaging of breast 3D US volumes with bi-dimensional US scans. A Motion Control Sensor enables the correction of the examined subject's movements. Data about fusion precision and system performances will be presented regarding tests in vitro, in ex-vivo and in vivo.**

I. INTRODUCTION

Due to increased breast cancer consciousness, breast examination both for screening and second level of investigation has spread worldwide. Thus, different diagnostic imaging technologies emerged in breast application: Magnetic Resonance Imaging (MRI) dedicated to breast [1], Automated Breast Ultrasound Systems (ABUS) with the patient in supine [2] or prone position [3], Mammography [4], Breast Tomosynthesis [5], Ductography [6] and Molecular Breast Imaging (MBI) [7]. Free-hand Ultrasound (US) plays an important role in breast diagnostics being a real-time examination, not ionizing and non-invasive, cost effective, ideal also for repetitive follow-up and able to give information about anatomy (B-Mode modality), hemodynamics (Color and Pulsed Wave Doppler) [8] [9] and tissue stiffness (Elastosonography [10]).

One of the most important concerns related to US breast imaging, regarding mostly when a sonographer performs the scanning, the Medical Doctor makes the diagnosis and an intervention on the examined area has to be performed, is the lack of anatomical reference points and landmarks of the acquired bi-dimensional US scan, for an easy and fast recognition of the area of interest and its localization. In the actual daily clinical practice the description of the site of a lesion should include the breast quadrant, the clock-face direction and the distance from the nipple [11], in order to recover as precisely as possible in operator's mind the position of a potential lesion. This limitation is related to US but not to other "naturally" three-dimensional (3D) imaging modalities, such as Breast MRI, but they have the drawbacks of high costs, longer acquisitions time, no real-time examination, no hemodynamic and strain tissue evaluation capabilities.

Common fusion imaging registration procedures between US and a second imaging modality such as MRI, Computed Tomography (CT) or Mammography, even if considered one of the breast image registration techniques [12], have the major disadvantage that the patient's position is different between the two imaging modalities (US and MRI/CT/Mammography), that is supine for US and prone or standing, with the breast possibly compressed, for the second imaging modality. This different position and/or breast tissue compression create breast tissue deformations and differences in tissue and lesions displacement [13, 14]. Even if mathematical models tried to solve the problem [15], up today there are no final clinically accepted solutions for breast deformation reconstruction among different diagnostic imaging modalities.

The present work describes the innovative 3D Panoramic (Pan) tool of Virtual Navigator technology for the real-time fusion imaging of breast 3D US volumes with bi-dimensional US scans. Tests regarding the fusion precision between the 3D US volume and the 2D US scans will be presented in vitro. Furthermore, the procedure was enhanced by a Motion Compensation (MC) technique, using a Motion Control Sensor (MCS), which corrected possible subject's voluntary, or involuntary (e.g. respiratory) movements, for patient's and sonographer's increased comfort and easier US scanning. Additional tests regarding 3D Pan imaging capabilities and practical use and usefulness both in ex-vivo and in vitro, will be presented as well.

II. MATERIAL AND METHODS

A. Subject Predisposition

In vitro tests regarding image fusion registration precision were performed with commercially available breast phantom with amorphous lesions (Model 052A, CIRS - Computerized Imaging Reference Systems Inc., Norfolk, Virginia, USA).

For ex-vivo fusion imaging tests, a hand-made phantom, prepared with a chicken breast and an olive (with pit), was used. The chicken breast wanted to be a human breast tissue simulator, while the olive with pit wanted to be a solid breast mass simulator.

For in vivo real-time fusion imaging breast test, 8 female patients with suspected breast lesions or for their follow-up (mean age = 32, range = 30-47) underwent US examination, after signing a written informed consent. The subject was lying on the examination bed, placing her arms above and behind her head, in order to keep the breast as stable as possible and in order to easily reach the axilla for examination.

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B. Image acquisition

For all the examinations an Esaote MyLabTwice US system (Esaote S.p.A., Genova Italy), equipped with Virtual Navigation option [16], allowing real-time image fusion of 3D US with 2D US scans, was employed. Moreover, Esaote LA923 and LA533 Linear Array Probes (LA923 - Operating Bandwidth: 4-13 MHz; CFM-PW Frequencies: 4.5 - 5.6 - 6.3 – 7.1 MHz; LA533 - Operating Bandwidth: 3-13 MHz; CFM-PW Frequencies: 3.6 - 4.5 - 5.6 - 6.3 – 7.1 – 8.3 MHz) with different reusable tracking brackets with sensor mounted (Esaote Virtual Navigator dedicated support for LA923 and CIVCO 639-042 for LA533 - CIVCO Medical Solutions, Kalona, Iowa, USA) were used. LA923 probe has an array width of 105 mm and it was mainly used for a fast acquisition of large volumes. LA533, 53 mm array width was mainly used for small breast volumes acquisition and 2D US examination. LA533 probe has a dual-possibility hand grip design, pinch grip and palmar grip (appleprobe design), in order to provide a neutral wrist position [17]. This resource represented an additional operator's comfort option during long examinations. Virtual Navigator real-time fusion imaging between 3D and 2D US data on the US system was possible by an electromagnetic tracking system, consisting of a transmitter on a fixed position, a small receiver mounted on the US probe through a dedicated support and the MCS, applied on the examined target (in this case the patient's sternum). A twisting of the sensor cable and a blockage with plaster strips were made in order to maintain the MCS, as steady as possible. The transmitter, whose position is considered the origin of the reference space system, corrected by the data coming from the MCS, was kept steady by a proper support, while the position and the orientation of the US probe in the created 3D space is provided by the receiver unit. The electromagnetic field source tip was oriented to point the target, the subject's breast, in order to address the highest intensity and the most homogeneous area of the created electromagnetic field on the US scanning area. The magnetic field produced by Virtual Navigator electromagnetic tracking system is stronger at the transmitter site and it fades with distance from the transmitter: the magnetic field is lower than the Earth's magnetic field at a distance of 78 cm from the transmitter, therefore the MCS movement freedom was possible within 78 cm. A non-metallic table was used to reduce as much as possible the interferences with the created electromagnetic field. The MC precision test was already performed and described in a previously published study [18].

C. 3D Pan and Fusion Imaging Procedure

Before starting the 3D Pan procedures, a check of the accuracy of the electromagnetic field was performed: the same point coordinates were measured twice in two different spatial orientations by a dedicated registration pen, with the electromagnetic sensor mounted in. Accuracy lower than 0.2 cm was considered acceptable.

The 3D Pan tool, based on the electromagnetic field positioning capabilities of Virtual Navigator technology, already employed in other clinical applications [18], enabled the gluing of different 3D US breast tissue volumes and the navigation within. The operator had the possibility to use the large width array transducer (LA923) and to shift to the LA533 probe with higher maneuverability, for detailed analysis of the targets (possible lesions, suspect echographic signs, etc.) by simply changing the probe. A thick layer of US gel (Aquasonic 100, Parker Laboratories Inc, Fairfield, New Jersey, USA) was used to ensure a complete coupling between the transducer and the examined subject's skin, to avoid black cones and dark areas on the US image and to prevent excessive pressure on the examined area, in order not to change the breast tissue shape and position.

Custom color targets were placed on the acquired 3D US volume, in order to identify the areas that have to be scanned more precisely, using different tools for increased diagnostic confidence: Elastosonography, Color Doppler, Power Doppler.

3D Pan reconstruction and gluing algorithm of different US volumes could work using two different processes: "Preview" made a 3D global reconstruction, based only on the geometric and position information given by the probe position and orientation within the Virtual Navigator electromagnetic field, while "Auto", in addition to the information coming from the tracking system, performed a data analysis focused on tissue structure recognition, in order to find the best matching between the volumes. This could be particularly useful to compensate small movements, due to breathing and/or little tissue compression by the US probe during scanning. Major tissue deformation leads to a failure of the automatic gluing process.

III. Results

Virtual Navigator 3D Pan tool fused different 3D US B-Mode and/or three dimensional Color Doppler or Power Doppler volume acquisitions: in the tests of this work only B-Mode acquisitions were performed. 3D Pan tool made the fusion of two or more US volumes acquired by an electromagnetic tracked free-hand acquisition; in order to ensure a visual continuity to the acquired volumes, a proper level of overlapping of one volume and the adjacent one was needed (5mm were considered sufficient).

The scanning velocity during Virtual Navigator 3D Pan acquisitions didn't affect the reconstruction, as in the conventional 2D US panoramic imaging not electromagnetically tracked, where the quality and the dimension – length - of the final merged image is related to the acquisition scanning velocity. Furthermore, Virtual Navigator electromagnetic tracking technology enabled monodirectional scanning, without paying attention to the velocity of transducer movement.

Seven tests to assess the registration phase precision between 3DPan volume datasets and 2D US scans were performed on the breast phantom with amorphous lesions. Four tests were performed placing the phantom at a fixed distance of 45 cm from the Virtual Navigator transmitter (distance measured from the center of the electromagnetic transmitter to the center of the phantom), repeating the 3D Pan acquisition phase each time and measuring the axial, coronal and sagittal views of three targets for each registration.

Results are shown in Table 1. The maximum average error was 2 mm.

TABLE I. VIRTUAL NAVIGATOR 3D PAN PRECISION REPEATING ACQUISITION, SAME PLACE

Acquisition	Measured point	Registration error axial plane (mm)	Registration error coronal plane (mm)	Registration error sagittal plane (mm)
1	A	1	1	1
1	B	0	2	2
1	C	2	2	2
2	A	1	2	2
2	B	1	2	2
2	C	0	2	1
3	A	0	1	1
3	B	1	2	2
3	C	0	2	0
4	A	0	0	2
4	B	1	2	1
4	C	0	2	1

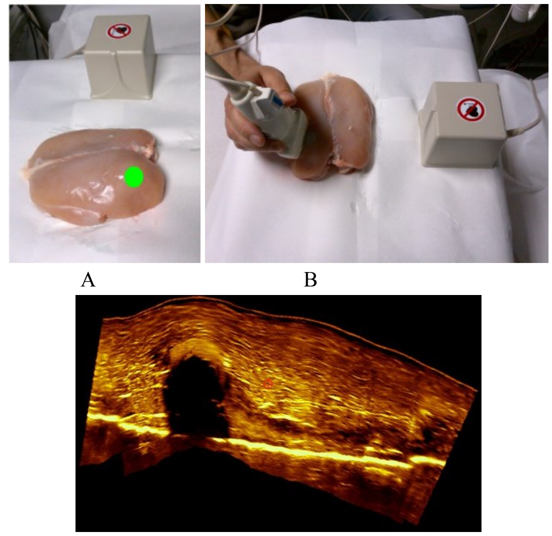
Three tests were then performed placing the breast phantom at different distances from the Virtual Navigator electromagnetic transmitter (36 cm, 45 cm and 53 cm), repeating a 3D Pan acquisition procedure after each distance change and measuring the axial, coronal and sagittal views of one target for each registration. Results are shown in Table 2. The maximum average error was 2 mm.

TABLE II. VIRTUAL NAVIGATOR 3D PAN PRECISION REPEATING ACQUISITION, CHANGED POSITION IN SPACE

Acquisition	Measured point	Registration error axial plane (mm)	Registration error coronal plane (mm)	Registration error sagittal plane (mm)
36 cm distance	A	1	1	1
45 cm distance	A	2	1	0
53 cm distance	A	2	1	1

The 3D Pan average acquisition error measured on the breast phantom with amorphous lesions is independent by the distance from the electromagnetic transmitter, remaining in the field limits of 78 cm [18]. The average 3D Pan precision error related to different acquisitions was 1.25 mm. All the tests were performed reconstructing the 3D Pan US volumes and fusing them employing the "Preview" algorithm, because no anatomical landmarks where present within the breast phantom with amorphous lesions. The acquisition time was set to 7 seconds for each volume, for a total of 2 volumes acquisition for each test.

The ex-vivo performances tests of the Virtual Navigator 3D Pan tool were performed on the Chicken Breast Phantom (CBP) with an olive (with pit) as Lesion-Like Target (LLT). Chicken breast phantom was scanned longitudinally, acquiring three US volumes (22 seconds scan time for each US 3D acquisition). Acquired US volumes were then fused together with 3D Pan tool, in order to obtain a panoramic volume of almost half CBP containing the LLT (Fig. 1). The obtained Pan volume was achieved with the "Auto" gluing algorithm. A surface shift after the US volumes gluing was noted: the reason of this shift can be found in the pressure applied on the probe during the CBP volume acquisitions. Different tissue densities of the CBP areas can lead to different compressions during scanning. The Auto gluing algorithm, recognizing and matching the inner structures of the scanned volumes (focused on the re-alignment of inner structures) and leaving a discontinuity reconstruction only at the surface level, considered the "less interesting" part of the reconstructed volume.



A B

C

Fig. 1. A: Chicken breast phantom with the point where the olive with pit was inserted; B: 3D Pan volume acquisition; C: 3D Pan volume

The LLT and its surrounding tissues were examined also using elastosonography; tissue stiffness evaluation and the relative stiffness measurements (ElaXto Ratio) were performed on the LLT and the surrounding CBP areas. In terms of elasticity, the olive, with respect to the surrounding chicken breast, resulted 7 times harder, as measured with the ElaXto Ratio, where two Z-zones (Z1 and Z2) were traced on the ElaXto image and then the system provided a strain ratio, related to the tissues included in the traced Z-zones. The resulting value is directly proportional to the tissue elasticity included in zone Z2, compared to the one of zone Z1. The elastosonography evaluation of the LLT and the surrounding structures of the CBP stiffness was performed also during real-time simultaneous visualization of 2D US scan, fused with the glued volume US. Elastosonography helped the operator to clearly detect the LLT, being stiffer than the CBP surrounding tissues. Bi-dimensional US elastosonography examination was performed in different directions, scanning the CBP on several planes containing different LLT views, in order to include the whole area around the LLT (Fig. 2).

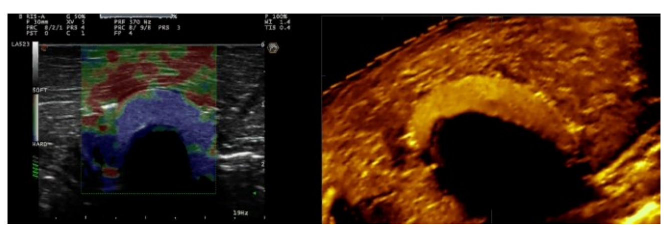


Fig. 2. Elastonography of the olive within the chicken breast phantom with the parallel co-registered view of the acquired 3D Pan volume

The in vivo tests were performed during routine US breast examinations, related to suspected breast lesions or to their follow-up. Two US volumes (15 seconds maximum scan time each) were acquired, using large width array

LA923 on 3 subjects, then fused together with 3D Pan tool and finally navigated with the more ergonomic LA533. On 5 subjects the Virtual Navigator 3D Pan tool was employed for the fusion of three volumes (15 seconds maximum scan time each) obtained directly with LA533 probe. The probe choice for the 3D Pan volume acquisition depended on the breast dimensions, morphology and the area to be reconstructed. The reconstruction of the axilla needed a large amount of gel. Virtual Navigator 3D Pan acquisitions were performed taking care to maintain an overlapping region among the different US volume acquisitions and to limit as much as possible the shadowing effect, due to poor probe-tissue coupling with consequent reduction in image quality, in order to obtain high quality B-Mode imaging in all the examined volumes. The scanning of the same volume from two different points of view was avoided, in order not to confuse the reconstruction algorithm. This case was possible, for example, when conventionally scanning an elongated breast: the nipple area was imaged from bottom to top and vice versa, acquiring the same structures twice.

The complete duration of the US breast examination was increased by about 5 minutes, due to the 3D Pan acquisitions. The MCS was used and positioned on the patient's sternum.

Custom color volumetric targets, visible on both 2D US and 3D Pan volume, were used in order to better identify the interesting areas (Fig. 3). Color Doppler, Power Doppler, Pulsed Wave Doppler evaluations were performed also during real-time simultaneous visualization of 2D US scan fused with the glued volume US, in order to make a hemodynamic assessment of the lesions and of the surrounding areas. Elastosonography was used in order to recognize breast stiffer regions and to perform elasticity measurement among different tissues.

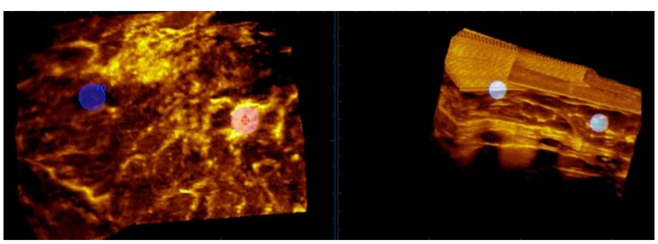


Fig. 3. Custom color volumetric targets within the 3D Pan volume

IV. Discussion and Conclusion

Virtual Navigator 3D Pan technology showed to be a reliable and easy tool that fused 3D US breast anatomical data with bi-dimensional US scans. Color Doppler, Power Doppler, Pulsed Wave Doppler and Elastonography evaluations were performed, while navigating within the 3D Pan volume, in order to respectively analyze the hemodynamic and stiffness characteristics of the examined area. Virtual Navigator 3D Pan tool worked in the breast and axilla areas as a sort of "target positioning system". Custom targeting of lesions and/or suspected areas allowed the operator to easily identify and spatially localize the targets, navigating within the whole picture given by the 3D panoramic view. The electromagnetically tracked free-hand acquisition enabled the operator to cover all the areas of interest. The possibility to acquire the US volumes with one large width array probe and the capability to navigate within the acquired 3D glued volume with another more ergonomic probe without any re-synchronization procedure between 3D and 2D views was a particularly appreciated feature.

The extended duration of the examination time for the 3D Pan acquisition was balanced by the increased level of confidence and the easier navigation within the 3D US volume for both the scanning operator and the Medical Doctor image reviewer.

For all the patients involved in the in vivo tests a satisfactory visual matching between the 3D Pan volume and the relative 2D US was obtained.

MCS is an innovative technology that corrects subject's movements, in order to simultaneously increase his/her and the sonographer's comfort and to ease US scanning procedures.

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