Evaluating Spatial Coverage of Breast Examination with Free-hand Ultrasound Transducer

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Abstract: Ultrasound examination plays an important role in both breast cancer screening and diagnostics. One of the drawbacks of the US examination is the uncertainty whether the whole breast was scanned. The proposed paper addresses the methodology how the completeness of the examination can be efficiently evaluated. We propose an affordable solution for simultaneously tracking and grabbing a video from a free-hand 2D ultrasound transducer during standard breast examinations by means of the probe motion tracking. From the recorded data we calculate duration in seconds, for which every part of the examined region has been captured and perform algorithmically local 3D reconstruction. Thus the system can inform the specialist performing the exam about regions that were insufficiently examined and minimize the risk of not detecting developing harmful lesions. The measure for the evaluation and comparison of the individual examinations is proposed. The functionality of the method is illustrated.

1 INTRODUCTION

Breast cancer is the most common malignancy in women and the second most common cause in cancer-related mortality. The widespread methodology for the breast cancer screening is mammography, which provides almost complete breast pictures at two projections with high sensitivity to microcalcification. Breast ultrasound (US) is often used to evaluate breast problems that are found by a mammogram, especially for women with palpable lesions on physical exam or with dense breast. For the latter situation, the study (Boyd et al., 2007) revealed that extensive mammographic density, which is the case in more than 50 % in the age group under 60 (for younger woman this reaches even 75 %), is reproducibly associated with an increased risk of breast cancer. Here, the role of the US exams is hardly replaceable. US aids in distinguishing normal findings such as cysts or fat lobules from suspicious breast changes that require biopsy. It helps to better evaluates the lymph node involvement. Nevertheless, the US examination cannot be used as the sole one because of the inappropriate high false negative rate. The current trend is to use a combined set of diagnostic techniques for detection of breast cancer, usually mammography and US, recently also magnetic resonance imaging (MRI) or dedicated breast CT.

The US examination is painless and does not expose patients to radiation. On the other hand, the use of US for breast cancer screening is often limited by experience and skills of examiners, resolution of device, and, last but not least, by the length of examination. An important, albeit usually overlooked, drawback of the US examination is the uncertainty whether the whole breast has been scanned. There was an attempt to assess the completeness of freehand breast ultrasound scans (Andrei et al., 2014) using the breast phantom in simulated clinical exams.

The purpose of the work presented in this paper is twofold: first, it is intended as a base for development of a system for systematic evaluation of breast coverage, which will essentially provide feedback on breast coverage. Second, the system is expected to provide, using 2D scans and the data from a tracker, a 3D reconstruction of breast examination, with better depiction of lesions.

There have been numerous attempts to reconstruct 3D data from the handheld US probe, either based on

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a solely algorithmic support (Yu et al., 2011) or using some kind of tracking device for the 3D data composition (Huang et al., 2005; Huang and Zheng, 2008; Coupé et al., 2005). Recently, even the 3D volumes were proposed to be registered by software methods (Dyer et al., 2014) to obtain more complex representation of the scanned scene. Very good overview of existing approaches can be found in (Gee et al., 2003). Finally, it should be noted that there are 3D ultrasound systems working in an automatic manner (automated breast ultrasonography - ABUS) (Shin et al., 2015), too. 3D ultrasound is considered as promising new technology, especially applicable to screening for breast cancer in women with dense breast tissue. However there are certain limitations in acquisition geometries and in price level, which could limit application of such equipment.

The rest of the paper is organized as follows. Sec. 2 describes the proposed US setup and measures. Sec. 3 shows first results that were achieved with our device and Sec. 4 concludes the paper.

2 METHODOLOGY

During a clinical breast exam, we record the ultrasound images and the position and orientation of the ultrasound transducer. For this purpose we use an off-the-shelf grabbing PC card in combination with a tracking device.

In the proposed system the probe position data are collected seamlessly without any need for human interaction so the specialist performing the exam is not distracted. With the help of the tracking system, we can estimate the location of the probe and its trajectory through the examined region, and from these data also the frequency and duration of visits.

The hardware setup used to acquire all the necessary data during ultrasound examination consist of a computer with a digital video grabber and an electromagnetic six degrees of freedom tracking system (TrakSTAR, Ascension Technology Corp., Shelburne, VT, USA). The electro-magnetic field generator, the reference sensor and the sensor mounted on the US transducer are connected to the computer through a control unit. The arrangement of the tracker sensors and reference points is outlined in Fig. 1. The accuracy of this technology is on par with the resolution of the ultrasound device.

The video grabber and the tracking system are controlled using the PLUS open-source software package (Lasso et al., 2014), which also allows to perform the necessary sensor and temporal calibrations (prior to examinations) and synchronization of video

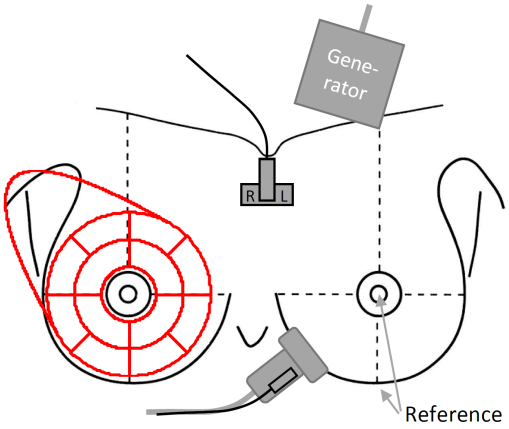


Figure 1: Outline of the system setup with defined reference points (two cross marks). Two electro-magnetic tracking sensors are used in the setup, one attached to the ultrasound transducer and the “Reference” one, placed on patient’s sternum, which holds a ”Right-Left” plate. Predefined sectors for evaluation of an examination, for which the average time spent and the entropy are calculated, are outlined in red color.

and spatial data. The whole process of storing proper data during examinations is controlled by an in-house developed software. The software recognizes if the US image is “frozen” or not, which allows the physician to simply interact with the system (see Fig. 2).

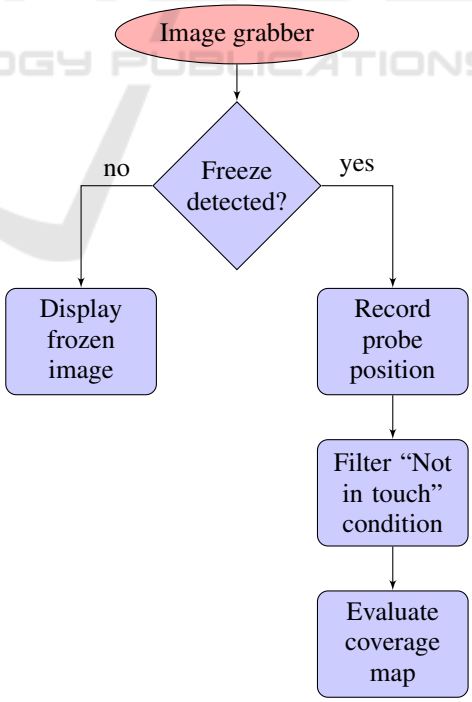


Figure 2: Operation modes of the coverage mapping system.

Considered from the physician’s perspective, the

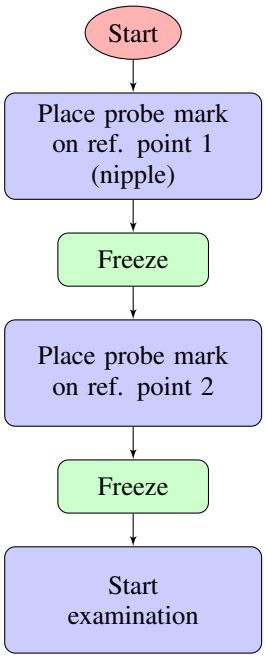
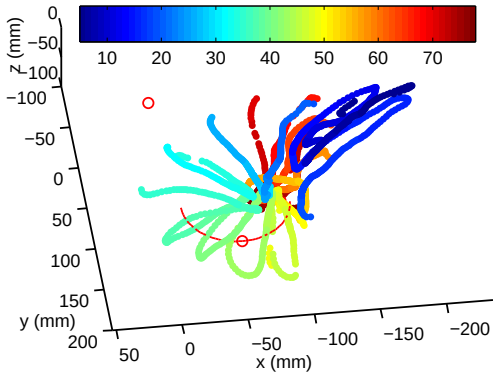


Figure 3: Calibration of the tracker system. Reference point 1 is located at breast nipple, refernce point 2 is located on the border between lower part of breast and the chest.

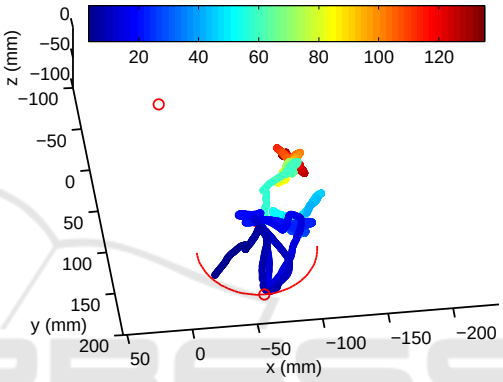
whole examination runs as follows: the physician places the reference sensor on patient's sternum under jugulum and using computer, starts the tracking system. He records the position of the two reference points (Fig. 1) by placing the "marked" side of the transducer on each point and pressing the "freeze" button. This allows us to calibrate the coordinate system for the breast position (see the chart in Fig. 3). Then the standard examination proceeds during which the transducer is continuously tracked and images are automatically stored with the maximum frame rate of the ultrasound system (typically around 30 FPS). Locations of potential findings can be easily stored by pressing the "freeze" button anytime during the examination. The acquired data sequence (transformation matrices and US images) is pruned to get only the valid part. Typically, any data corresponding with the periods when the transducer was not in touch with the body are removed.

Transducer Trajectory Visualization

The valid data are analyzed in the 3D reference coordinate system ($\mathcal{R}$) defined by the reference sensor and its axis, which coincides well with standard anatomical planes. Choosing the coordinate system of the sensor attached to a patient eliminates respiratory or other body motion. Let us denote the coordinate system of US image acquired at time t by I_t. The



(a) Screening



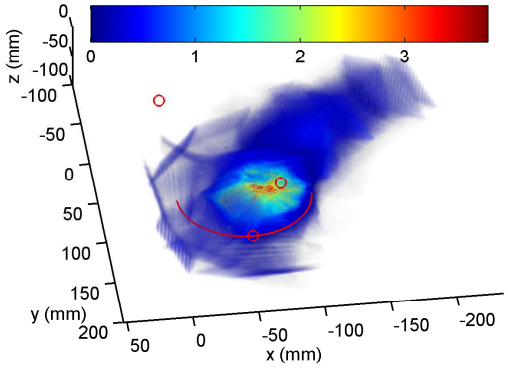
(b) Diagnosis

Figure 4: Color-coded trajectory of the probe center on skin during (a) screening examination and (b) diagnostic examination (focused on suspect breast region). Colors show time in seconds. The coordinate system in millimeters is defined by the reference sensor (origin denoted by the left-top circle) and the position of the breast is marked by the semicircle curve, which is calculated from the reference points.

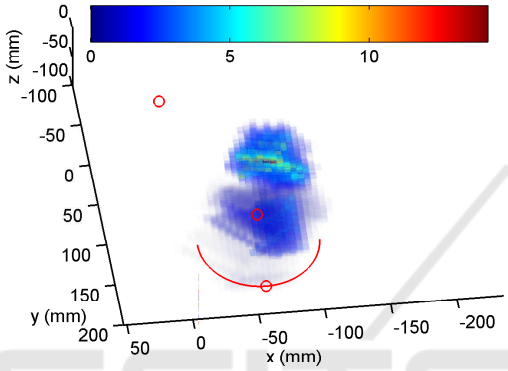
tracking device calculates a geometrical transformation $T_t : I_t \rightarrow \mathcal{R}$ that maps image pixels at time t to the reference coordinate system. The transformation T_t allows us to provide several useful visualizations: to display the transducer trajectory in $\mathcal{R}$, we apply T_t to the central pixel of the image in I_t and plot the 3D points with color mapping derived from time t. Examples are given in Fig. 4.

Visualization of Examination Coverage

An important task is the visualization of time spent in each part of the breast and adjacent tissues. In other words, we want to know how frequently every location of $\mathcal{R}$ has been captured in the images. This is done by voxelization (discretization) of the reference coordinate system $\mathcal{R}$. Each voxel coordinate is transformed by the inverse T_t^{-1} to I_t, the voxel value is incremented if it lies in the respective image domain



(a) Screening



(b) Diagnosis

Figure 5: Time in seconds (coded in color) spent in breast and adjacent lymph nodes voxels during (a) screening examination and (b) diagnosis examination. The coordinate system in millimeters is defined by the reference sensor (origin denoted by the left-top circle), the breast position is marked by the semi-circle curve and by the other two circles that represent the reference points (cf. Fig. 1).

and this is done for all t. The resulting 3D array, denoted as S, represents the number of images crossing each voxel. To estimate the time spent in each voxel, we divide the array by FPS; see examples in Fig. 5.

Evaluation of Physicians

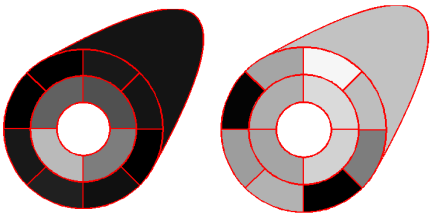
We collect data from different physicians performing screening examinations with an aim to compare their performance (and diligence). The reference points are used to co-register different examinations from the same physician as well as examinations of various physicians. The proposed method does not provide full registration but the results demonstrated enough accuracy for mutual comparison. The registered surfaces are divided into angular and circular sectors c_i (Fig. 1, red structure) and in each sector the average time spent $\bar{S}(i) = |c_i|^{-1} \sum_{x \in c_i} S(x)$ (Fig. 6 - left) and density of coverage D (Fig. 6 - right) is calculated, where $|c_i|$ is the area of the i-th circular/angular sector. The density of coverage is estimated by calculating the entropy in sectors. If $S(x)$ is the time spent in position x, then $D(i) = -(\ln |c_i|)^{-1} \sum_{x \in c_i} S(x) \ln S(x)$. More homogeneous coverage in a sector implies higher density D. Both $\bar{S}(i)$ and $D(i)$ is averaged over all examinations from each physician and then we compare different physicians by comparing the averaged values.

3D Reconstruction

Finally, using the tracker system, it is possible to perform local 3D reconstruction of the breast image. Unlike in the visualization of the "time-spent", it is more convenient here to work with the original transformation T_t. For all t, every image pixel in I_t is transformed to discrete $\mathcal{R}$. The pixel values in $\mathcal{R}$ are calculated either with the nearest-neighbor or linear interpolation. If collisions occur and more than one pixel transforms into the same voxel, it is possible to apply a maximum or a mean rule. Holes, i.e. empty voxels, can be filled by propagating values from neighboring voxels, an analogy to inpainting. The US transducer must be in contact with skin, which causes unwanted tissue deformation. Due to tissue elasticity it is unrealistic to perform 3D reconstruction of the whole breast. However, we are able to run 3D reconstruction on small areas covering potential findings. The potential findings are stored as a list of time instances t_f's, for which the "freeze" button was pressed. We assume that in short time intervals (couple of seconds) the transducer motion is continuous and the differences in tissue deformation are negligible. We then select such short time intervals around each t_f and consider only images in these intervals for 3D reconstruction.

3 EVALUATION

Our tracking and visualization setup is currently being tested in a Prague, CZ-based mammography center. We are collecting data from different physicians performing both diagnostic and screening examinations on patients of various ages. Our goal in the first stage is to collect enough data for statistical analysis of different screening methodologies. In the next stage, we plan to deliver a solution (computer-aided diagnosis), which would inform the physician of regions inadequately examined, store the exact position of potential findings for future references, and perform local 3D reconstruction to improve automatic or semi-automatic detection and classification of the findings.



(a) (b)

Figure 6: Evaluation of the screening quality: left - time spent in sectors - lighter color means longer time; right - density of coverage in sectors - lighter color means more homogeneous examination with less holes (neglected regions).

We demonstrate the visualization output of the US setup on two real examples. The first one is a screening examination, during which the whole breast and adjacent lymph nodes should be covered. The second one is a diagnostic examination, during which the physician focuses only on areas with earlier findings. The transducer trajectory for both examinations has been shown in Fig. 4. The trajectory is rendered in the reference coordinate system $\mathcal{R}$ and the time is coded in color. In the screening example Fig. 4(a), the physician started in the axillary lymph nodes and continued with a systematic examination of the breast from the areola to its sides. In the diagnostic example Fig. 4(b), only a small section of the breast is covered. The differences between both examinations are even more noticeable in our second type of visualization in Fig. 5, which shows the time spent in each voxel. The voxel color denotes the duration in seconds, for which the corresponding area has been examined. We use semitransparency of voxels to better visualize the volume. Note that in the screening example Fig. 4(a) the most frequently visualized area is the areola, whereas in the diagnostic example it is the area of the earlier finding, which in this case is in the upper outer quadrant. In addition, we can perform 3D reconstruction of the area and apply segmentation algorithms to 3D reconstruction, such as GrowCuts (Zhu et al., 2014), and visualize present lesions as shown in Fig. 7.

4 CONCLUSION

We have proposed an affordable enhancement of US devices, which is currently being clinically tested. An electro-magnetic tracking technology is used to simultaneously track the position of a patient and a free-hand US transducer, which allows us to perform several visualization tasks. We can for example display spatial distribution combined with duration, for which every location in our 3D space has been examined.

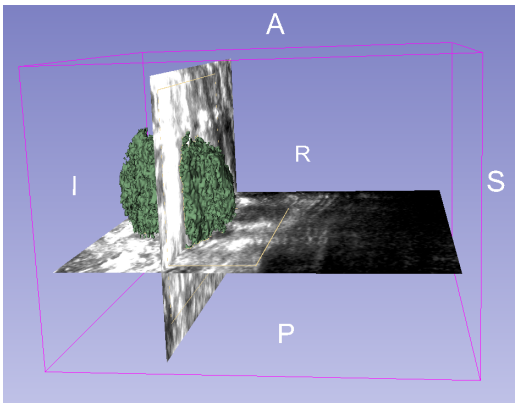


Figure 7: Example of 3D segmentation using GrowCuts.

The advantages of the proposed setup are twofold. We can perform blind tests and evaluate physicians during US examinations or we can guide the physicians to regions insufficiently examined and show 3D reconstruction of lesions.

Possible alternative to using the electro-magnetic tracker would be to use an optical tracking system, such as the Microsoft Kinect. In our opinion, however, the E-M tracker provides more robust operation with more accurate data, and, with fewer requirements on positioning, direct visibility, etc., it imposes less stress both on the expert performing the examination, and on patient. Furthermore, using some video tracking system, additional ethical issues could possibly arise.

Future work includes an evaluation study of examination procedures over a larger number of specialists and patients.

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REFERENCES

Andrei, S. S., Gao, J., Chiu, J., Turian, J., and Caluser, C. (2014). Performance evaluation of an automated free-hand breast ultrasound system for the completeness of scanning assessment. *European Congress of Radiology*, C-1382.

Boyd, N. F., Guo, H., Martin, L. J., Sun, L., Stone, J., Fishell, E., Jong, R. A., Hislop, G., Chiarelli, A., Minkin, S., and Yaffe, M. J. (2007). Mammographic density and the risk and detection of breast cancer. *New England Journal of Medicine*, 356(3):227–236.

Coupé, P., Hellier, P., Azzabou, N., and Barillot, C. (2005). 3D freehand ultrasound reconstruction based on probe trajectory. *Medical image computing and computer-assisted intervention: MICCAI International Conference on Medical Image Computing and Computer-Assisted Intervention*, 8(Pt 1):597–604.

Dyer, E., Ijaz, U. Z., Housden, R., Prager, R., Gee, A., and Treece, G. (2014). A clinical system for three-dimensional extended-field-of-view ultrasound. *The British journal of radiology*.

Gee, A., Prager, R., Treece, G., and Berman, L. (2003). Engineering a freehand 3d ultrasound system. *Pattern Recognition Letters*, 24(4–5):757 – 777.

Huang, W. and Zheng, Y. (2008). MMSE reconstruction for 3D freehand ultrasound imaging. *International Journal of Biomedical Imaging*, 2008(1):1–9.

Huang, W., Zheng, Y., and Molloy, J. a. (2005). 3D ultrasound image reconstruction from non-uniform resolution freehand slices. *ICASSP, IEEE International Conference on Acoustics, Speech and Signal Processing - Proceedings*, II:125–128.

Lasso, A., Heffter, T., Rankin, A., Pinter, C., Ungi, T., and Fichtinger, G. (2014). Plus: Open-source toolkit for ultrasound-guided intervention systems. *IEEE Transactions on Biomedical Engineering*, (10):2527–2537.

Shin, H. J., Kim, H. H., and Cha, J. H. (2015). Current status of automated breast ultrasonography. *Ultrasonography*, 34(3):165–172.

Yu, H., Pattichis, M. S., Agurto, C., and Goens, M. B. (2011). A 3d freehand ultrasound system for multi-view reconstructions from sparse 2d scanning planes. *Biomedical engineering online*, 10(1):7.

Zhu, L., Kolesov, I., Gao, Y., Kikinis, R., and Tannenbaum, A. (2014). An effective interactive medical image segmentation method using fast GrowCut. In *MICCAI Workshop on Interactive Medical Image Computing*.