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Novel Assistive Device for Tomographic Ultrasound Neck Imaging vs. Freehand

Abstract: For assessing clinically relevant structures in the neck area, especially the thyroid, it has been shown that 3D or tomographic ultrasound (3D US or tUS) is able to outperform standard 2D ultrasound [1] and computed tomography [2] for certain diagnostic procedures. However, when using a freehand and unassisted scanning method to acquire a 3D US volume data set in this area overlapping image slices, a variation of the probe angulation or differences in training might lead to unusable scanning results. Based on previous works [3] [4] we propose the design - with subsequent testing - of an assistive device that is able to aid physicians during the tUS scanning process on the neck. To validate the feasibility and efficacy we compared the image quality of both freehand and assisted scanning.

Keywords: Tomographic Ultrasound, Assisted Freehand Scanning, Thyroid Assessment.

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1 Introduction

Conventional 2D Ultrasound (US) B-mode imaging can be used for initial diagnostic procedures concerning soft tissue structures like the salivary glands or the lymph nodes [5] or to detect and analyze thyroid nodules. These US images could be the base for creating a three-dimensional volume model by accurately tracking the transducer/probe position during the scanning process and combining both the position and the image data to perform volume reconstruction and visualization [6].

Imaging systems that utilize this method are called 3D or tomographic ultrasound systems (tUS). Tomographic ultrasound systems are classified inconsistently in the

available literature [5] [7] [8]. According to [7] there are four methods for acquiring the required image and position data: 2D array transducers, mechanical 3D probes, mechanical localizers and freehand scanners. The freehand scanning method works by using a conventional 2D ultrasound transducer and equipping it with a tracking device. This approach enables the user to manually guide the US probe over the region of interest (ROI) in desired directions and positions. In this scenario, freehand scans mean unassisted scan acquisitions. There are many different tracking devices available that utilize a variety of physical principles and come with certain advantages and disadvantages [9].

Electromagnetic (EM) tracking systems for example work based on the generation and measurement of electromagnetic fields and consist of a transmitter (also called 'field generator'), a six axis sensor and a processing unit [9] (see Figure 1) The transmitter, consisting of at least three orthogonally placed coils, serves as the origin of coordinates and generates a three-dimensional electromagnetic field. The processing unit controls the electric current flowing through the coils and each field is simultaneously measured by sensor coils. The position and orientation of the sensor, and with that of the probe, is then calculated by continuously measuring the relative changes of the electromagnetic field during the probe movement. This type of tracking system is not negatively affected from line of sight issues, but can only be used within relatively short distance from the origin of coordinates. Other tracking mechanisms include optical, inertial and mechanical tracking [9].

Using the freehand acquisition method in general and specifically on a vaguely cylindrical object like the neck is strongly dependent on the individual ability of the user. Acquisition speed, applied pressure, and probe angulation can negatively impact scan quality and reproducibility. Additionally, effects like motion artefacts and overlapping

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image slices are likely to occur reducing the quality of the 3D volume even further [3].

Figure 1: Working principle of a freehand tUS system utilizing the electromagnetic tracking method (based on [7])

A possible solution to these problems was proposed in [3] and [4]. Designing assistive devices that guide an US probe and tracking sensor around the neck on a fixed circular path during the scanning process improved the image quality compared to a non-guided freehand scan. However, these prototypes were not able to generate usable results for diagnosis and needed to be improved. Based on those initial results this paper deals with the use of a systematic designing approach to conceptualize and build an improved prototype for assisted 3D US acquisitions.

2 Materials and Methods

The designing guideline VDI 2221 by the Association of German Engineers [11] was used as a structured and methodical approach for creating a usable prototype. This designing approach starts with a systematic task analysis to generate a comprehensive list of requirements and boundary conditions for the design. Based on this list (sub-) functions are determined that need to be fulfilled by the design. Different modular concepts to fulfil those functions were created and evaluated.

The most important requirements were set as follows:

- patient's head / neck must be stable during the scanning process
- circulation radius of the US probe needs to be adaptable to fit different neck sizes
- design must not include any magnetic parts materials because of their interference with the electromagnetic tracking system
- device needs to be put on / taken off in 5 steps or less and without use of additional tools

To prevent any head / neck movement during the scanning procedure the prototype proposed in this paper was designed to be used on a lying patient on an examination table. Ideally

a 180° rotation should be realized with the center of rotation roughly in the center of the neck (Figure 2). Based on this concept and requirements a prototype was realized using standard parts, 3D printing and a milled acrylic arc (Figure 3).

Figure 2: Basic concept of guided neck scans

Figure 3: Designed prototype (1) item profile foundation and neck pillow; 2) acrylic glass arc; 3) 3D printed arc slide 4) linear slide; 5) 3D printed probe attachment; 6) PUIR tUS tracking sensor; 7) GE 9L US transducer; 8) gel pad filled with US transmission gel

The basis of this prototype is a foundation (1) made from non-magnetic item profiles and a plate. The patient's head is

placed onto during the scanning process. A detachable acrylic glass arc (2), working as a circular guide, is placed in the rails of the profiles allowing linear adjustment. Combined with a 3D printed arc slide (3) the required circular motion around the neck is realized. This slide also functions as a slot for the radial slide (4) that is needed to adapt the probe circulation radius to different neck sizes. To hold the US transducer (7) and the motion tracking sensor (6), a probe attachment (5) was designed, 3D printed and attached to the linear slide. To compensate unevenness's of the neck a gel pad filled with US transmission gel (8) was included in the design. Before the scanning process starts the pad is placed around the patient's neck. The circulation radius is adjusted and fixed by using a locking mechanism on the radial slide.

To validate the prototype test scans were obtained and the image quality compared to unassisted freehand scans with regards to motion artefacts and slice overlap. Furthermore, the carotid artery diameter was measured in both scans and compared to findings in [12].

The prototype was tested on 5 male subjects. The test setup included two scan acquisition approaches: freehand tUS scans and assisted scans with the prototype. The freehand scans were performed using an US system (9L probe and Logiq e GE Wisconsin, USA) coupled with an EM tracking and reconstruction system (PIUR Imaging, Vienna, Austria). The same systems along with the prototype were used to conduct the assisted scans. Parameters such as gain, depth and probe frequency were adjusted based on the subject being scanned.

3 Results and Discussion

The results from tests conducted on one of the subjects has been included. The results were analyzed qualitatively based on the image quality of the volume reconstructed first (Figure 4).

Here it can be seen that the freehand volume follows an uneven reconstruction pattern and in a large way does not depict a true representation of the neck and the structures within it.

Apart from this the reconstructed volume using the freehand method depicts deformation of structures and larger image overlaps. In comparison to this, the assisted method depicts a much more realistic representation of the neck and structures within it.

It also significantly reduces image overlaps and deformation of structures. This is attributed to the rigid structure of the prototype that disallows the application of larger force on the epidermis that causes deformation.

The second evaluation was a quantitative analyses. Therefore, a structure in 2D slices within the reconstructed neck volumes was selected and measured in both cases (freehand and assisted). The carotid artery was selected in this instance.

The common carotid artery was measured in individual US slices of sagittal plane–This can be seen in Figure 5.

Figure 4: Exemplary visual comparison of freehand (1a, 1b) and assisted 3D US scans (2a, 2b), top and tilted view of 2 volume reconstructions from one subject

Figure 5: Average measured diameter of one subject's common carotid artery in a) freehand and b) assisted scans

The average diameter of this artery in males is 6.52 ± 0.98 mm according to [10]. Both measurements, freehand 5.63 ± 1.13 mm and assisted 7.25 ± 0.58 mm, lie within this range. But there is a significant deviation of -1.61 ± 1.24 mm from one another. This might be due to applied pressure in combination with unfavorable quick changes in probe angulation during the freehand scan that left out the actual centerline of the artery. Further tests are necessary to see if and how the measurement differences change across multiple scans.

To conclude, experiments from both scanning methods generate measurable results. The difference lies in the reconstruction and subsequent visualization of the 3D volumes. Volume reconstruction and visualization from freehand scans appear more to have more irregularities and deformations. Assisted volumes depict a more uniform reconstruction and visualization. This is due to the fact that the probe always follows a 'standard' guided path. That makes it

a more suitable method to compare structural changes in the neck over an extended time period. Improving the prototype in terms of user friendliness (e.g. by including a cable guidance) and optimizing the use of the gel pad will be the next steps in creating a standardized method for reliably acquisition of 3D US scans. The reproducibility across varied demographics still need to be further investigated. The measurements of the carotid arteries in this study were done on individual 2D slices within the reconstructed volumes. This resulted in a small difference between the measurements. Further measurements and analyses in the 3D volumes itself (not individual 2D slices) need to be conducted, compared and extended to other structures within the neck such as thyroid, salivary glands, lymph nodes, etc. If this acquisition method and prototype can be further developed it could be also used for assessing other body parts like internal structures in the abdominal region.

References

- [1] L. W.-B., Z. B., Q.-L. Zhu und e. al., „Comparison between thin-slice 3-D volumetric ultrasound and conventional ultrasound in the differentiation of benign and malignant thyroid lesions,“ *Ultrasound in Medicine and Biology*, pp. 3096-3101, December 2015.
- [2] J.-w. Li, C. Chang, M. Chen, W. Zeng, Y. Gao, S.-c. Zhou, F. Wang, N. Hu und Y.-l. Chen, „Is Ultrasonography More Sensitive Than Computed Tomography for Identifying Calcifications in Thyroid Nodules?,“ *Journal of Ultrasound in Medicine*, p. 2183–2190, 01 October 2016.
- [3] E. J. G. Ataide, J. Ziegler, M. Kalmar, A. Boese und M. Friebe, „Assistive Scanning Brace for Improved 3D Tomographic Ultrasound Neck Scans,“ in *40th International Engineering in Medicine and Biology Conference*, Honolulu, USA, Juli 2018.
- [4] E. Ataide, J. Ziegler, M. Kalmar, S. Rathi, A. Boese und M. Friebe, „Feasibility and Initial Results of Standardized US Scan Acquisition for Improved Tomographic Visualization,“ in *IEEE INDICON*, Gujarat, India, 2019.
- [5] J. E. Langer, S. Mandel und M. Milas, *Advanced Thyroid and Parathyroid Ultrasound*, Springer International Publishing, 2017.
- [6] D. Barry, C. P. Allott, N. W. John, P. M., Mellor, P. A. Arundel, D. S. Thomson und J. C. Wateron, „Three-Dimensional Freehand Ultrasound: Image Reconstruction and Volume Analysis,“ *Ultrasound in Medicine & Biology*, Bd. Vol. 28, Nr. 8, pp. 1209-1224, 1997.
- [7] Z. Z. Q. Huang, „A Review on Real-Time 3D Ultrasound Imaging Technology,“ *BioMed Research International*, Bd. March 2017, pp. 1-20, 26. March 2017.
- [8] L. C. R. L. E. Bozzi, „US Image Acquisition,“ in *Image Processing in Radiology - Current Applications*, Heidelberg, Germany, Springer Science+Business Media, 2007, pp. 3-12.
- [9] D. E. O. Dewi, M. M. Fadzil, A. A. M. Faudzi, E. Supriyanto und K. Lai, „Position Tracking Systems for Ultrasound Imaging: A Survey,“ in *Medical Imaging Technology - Reviews and Computational Applications*, Singapore, Springer Science+Business Media, 2015, pp. 57-89.
- [10] R. Slapa, W. Jakubowski, J. Slowinska-Srzednicka und K. Szopinski, „Advantages and disadvantages of 3D ultrasound of thyroid nodules including thin slice volume rendering,“ *Thyroid research* vol. 4, 1 1, Bd. 4(1):1, pp. 1-12, 7 January 2011.
- [11] A. o. G. E. (VDI), *VDI 2221 - Systematic approach to the development and design of technical systems and products*, Duesseldorf, Germany: VDI-Gesellschaft Produkt- und Prozessgestaltung (VDI Product and Process Development incorporated), 1993.
- [12] J. Krejza, M. Arkuszewski und S. Kasner, „Carotid Artery Diameter in Men and Women and the Relation to Body and Neck Size,“ *Stroke*, Nr. 37, pp. 1103-1105, 2006.