The mapping of the vertical target position is divided into the region above and the region below the tool. When the target lies above the tool, the amplitude envelope of the Shepard tone alters periodically, indicated by the gray arrow in Fig. 1. This amplitude fluctuation creates the perception of beating [5]. Here, the vertical distance (Δy) is mapped to the amplitude modulation frequency with a maximum lying well below 15 Hz, where the sensation of beating fades towards the perception of roughness [Ref]. When the target lies below the tool, a frequency modulation is performed instead of an amplitude modulation. To avoid conflicts with horizontal information, the frequency modulation is so fast that the result is not perceivable as frequency alteration but as steady sound. Here, Δy is mapped to the modulation depth which controls the number and amplitude of additional frequencies around the carrier frequencies. This affects the perceived noisiness/roughness [5].

A listening test with 7 subjects is performed to test the current state of development and to derive appropriate scaling ranges.

Seven non-expert subjects participated in the study. First, the sonification principle was demonstrated within a few minutes. Then, 19 test sounds were played, each indicating one of 16 potential locations which are left, right, up, or down, each either near or far. The subjects marked the guessed target location relative to a cross-hair. They had to choose one out of 16 fields on the map which is shown in the background of the plotted results in Fig. 2.

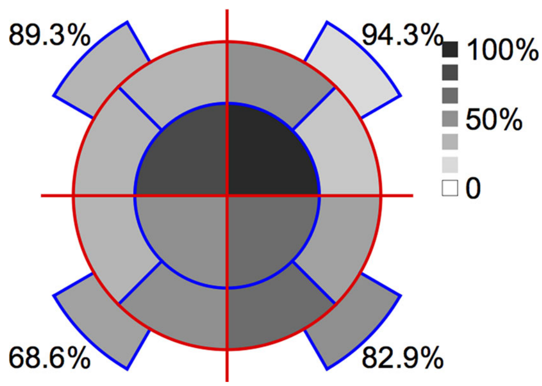

Fig. 2 Results of user test: gray level indicates how frequently a target field was localized correctly. The percentages in the corners indicate how frequently each of the 4 quartiles has been identified correctly by the subjects

Results

An overview of the listening test results is illustrated in Fig. 2. The gray level indicates how frequently a target field was localized correctly. The percentages in the corners indicate how frequently each of the 4 quartiles has been identified correctly by the subjects. Quartiles in the north are identified more often that quartiles in the south, quartiles in the east more frequently than in the west. This indicates that the rise in pitch is identified better than a falling pitch and that beating is superior to roughness/noisiness.

Near target fields tend to be localized best. Although the far target fields in the northeast quartile are rather rarely localized correctly, almost every subject identified the correct quartile in almost every trial. Here, the subjects tend to confuse fast pitch change with quick beating and vice versa. This effect can also be observed in the northwest quartile. In the near southwest, some subjects heard the subtle noisiness as slow beating. This situation improves at higher noisiness.

Conclusion

A psychoacoustic sonification approach has been introduced to assist in intraoperative placement of a tracked medical instrument. In an early stage of development, its aim is to guide the tool of a surgeon towards a target location by sonifying its direction and distance to the target in terms of psychoacoustic quantities. A listening test revealed that subjects could roughly identify most target fields after a short introduction to the system.

The results suggest some refinements of the mapping: The maximum beating frequency should be reduced so that it is clearly separable from the pitch shift. Furthermore, subjects had more troubles localizing near sources in the south compared to far sources. This indicates that the mapping range of roughness/noisiness should start at a higher degree of noisiness. Future work should apply the developed auditory display to the clinical scenario, such as tasks in endoscopy, bone drilling, or tracked needle placement.

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Integration of a surface scanner with an electromagnetic tracker for breast cancer surgery guidance

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Keywords Surface scanner · Electromagnetic tracker · Breast cancer surgery · 3D printing

Purpose

Nowadays, the standard procedure for lumpectomy in breast cancer surgery consists on using the wire-localization technique. Before surgery, the tumor is localized by a radiologist via ultrasound and a needle with a hook inside is inserted and fixed into the mass. Later in the intervention, the surgeon follows the path described by the hook to reach the tumor. This procedure, although effective, presents some disadvantages. The cost and time of the intervention increases and the aesthetic results could be improved by following a different path. Also, tumor may not be completely resected.

For these reasons, several studies have proposed ways to improve this procedure, making use of multimodal images or improving the guidance by navigating the surgical tools [1]. Nevertheless, the interpretation of the images or navigation scene is often difficult when no reference of what the surgeon sees from the patient is provided.

In this work a new technique for surgical navigation is proposed and evaluated, where the position of the tumor is represented together with the breast surface. The main purpose is to add relevant information to the virtual scene in order to facilitate its interpretation. An electromagnetic tracking system (EMTS) is used for needle guidance and tumor localization. The surface is obtained right before the intervention using a 3D surface scanner.

Methods

A structured light 3D surface scanner (Artec Eva) was used for acquiring breast surface and color data. An EMTS (Ascension 3D Guidance TrakSTAR) was used for tumor localization, where its position is inferred from the needle tip once inserted, as previously proposed [1]. An EMTS sensor was attached to the needle where the offset to the tip was obtained by pivot calibration.

In order to combine data sources we propose a registration procedure where 3 markers, localized in both systems, are placed near the patient's breast. The markers consist of 3 color prisms (red, green and blue) with dimensions 13 × 13 × 7 mm located on an L-shaped yellow reference with another EMTS sensor attached. Both markers and reference were 3D printed (BQ 3D Witbox 2) in polylactic acid. The position of the markers can be extracted from the 3D scanner data by color segmentation obtaining their center of mass. In the EMTS coordinate system they are obtained by selecting the center of every marker with a tracked pointer. After a landmark-based rigid registration the surface of the breast and the position of the tumor can be represented in the same space.

In order to assess the proposed workflow and evaluate the registration accuracy with respect to the landmark distribution, we performed several experiments placing the markers in 4 different positions around a breast phantom and measuring the Target Registration Error (TRE) in 33 points covering the breast surface (Fig. 1). These evaluation points were recorded with the tip of the needle in the electromagnetic space and localized in the scanned surface, generating two point clouds. Finally, both point clouds were compared in order to measure TRE. This procedure was repeated 6 times. A specific module was developed in 3DSlicer to perform the landmark extraction from the surface color data. All experiments were done using 3Dslicer for tracking purposes and also for measuring the registration error.

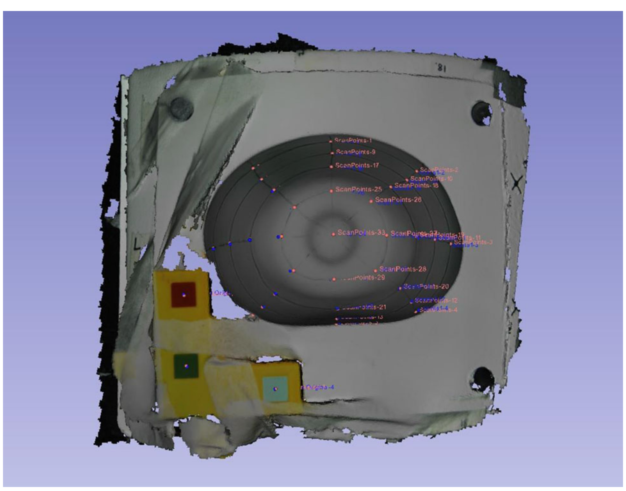

Fig. 1 Scanned surface with evaluation point clouds

Results

The Fiducial Registration Error obtained when registering the scanner and EMTS markers was below 0.45 mm, with mean error 0.22 mm. The TRE, measured comparing the point clouds, presented a spatial distribution with lower error close to the markers and larger as distance increases (Fig. 2), what is consistent with previous studies on fiducial-registration error. The mean error was 2.12 mm within the interval [0.54, 3.33]. These TRE values combine several sources of error: electromagnetic tracking, pivot calibration, color segmentation and scanner acquisition.

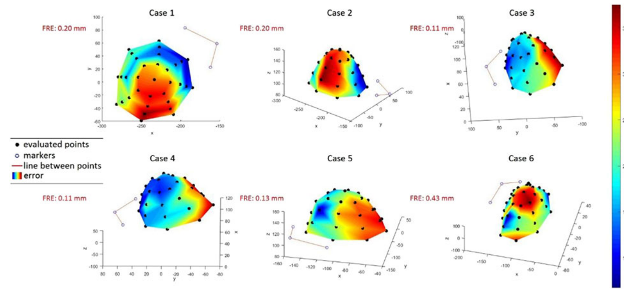

Fig. 2 Measured error for each evaluated case

Conclusion

Observing the results we can conclude that the procedure proposed for combining an electromagnetic tracker with a surface scanner is feasible, providing enough accuracy with errors around 2 mm over the working surface after the fiducial-registration process. Analyzing the error spatial distribution, an increase can be noticed in points away from the registration markers, meaning that the precision of the system is highly dependent on the markers position. However a bigger reference with more distributed markers would not be feasible in order to adapt to different patients.

As future work, a different design for the markers will be analyzed for reducing error. Also, once approved by the ethical committee, the procedure will be tested in real patients. Finally, this methodology may have other applications, including the validation of methods simulating the breast surface appearance in surgery [2], as well as other navigation scenarios.

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Comparison of auditory display methods for elevation change in three-dimensional tracked surgical tool

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