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Auditory Support for Image-Guided Liver Surgery

Purpose

The purpose of this work is to integrate concepts from the field of auditory display to enhance an electronic surgical navigation assistant for image-guided liver surgery. Although alarms and other auditory notification and monitoring devices are commonplace in operating rooms, audio has been a neglected modality in interaction with tools for intraoperative navigation. However, the conditions of the surgical environment present suitable opportunities for new aural modes of interaction. Surgeons and assistants are often charged with several tasks in parallel, including following a video monitor when using intraoperative planning tools. Auditory display provides a fast, flexible, and responsive system to reduce the overburdened dependence on visual input during surgery and allow surgeons to keep their eyes on the situs.

Methods

The current surgical navigation assistant allows for both preoperative and intraoperative surgical planning through the use of 3D liver models and intraoperative ultrasound data. The positions of surgical instruments (CUSA Excell, Integra Neuroscience) can be captured in real time using optical tracking and can be viewed on the 3D model. The surgeon needs to consult the planning system frequently, which creates distraction and possibly even confusion. At any rate, viewing the planning system's screen interrupts the surgical flow. Ideally, the surgeon would only need to look at the planning system if the instrument approaches a risk structure such as an important vessel system or tumor.

To address this issue, the auditory display for the surgical planning system makes use of risk maps (Fig. 1) with uniform safety margins surrounding risk structures such as vessels and tumors. Position data from the tracked CUSA are sent to audio synthesizer software, which references the risk map to indicate the distance of the instrument to the risk structures. The system alerts the surgeon when the instrument enters or exits each of three concentric precomputed uniform safety margins, emanating intuitive scaled layers of sounds. By using these auditory signals, the surgeon is better able to follow the preplanned resection plane, reducing dependance on the video monitor.

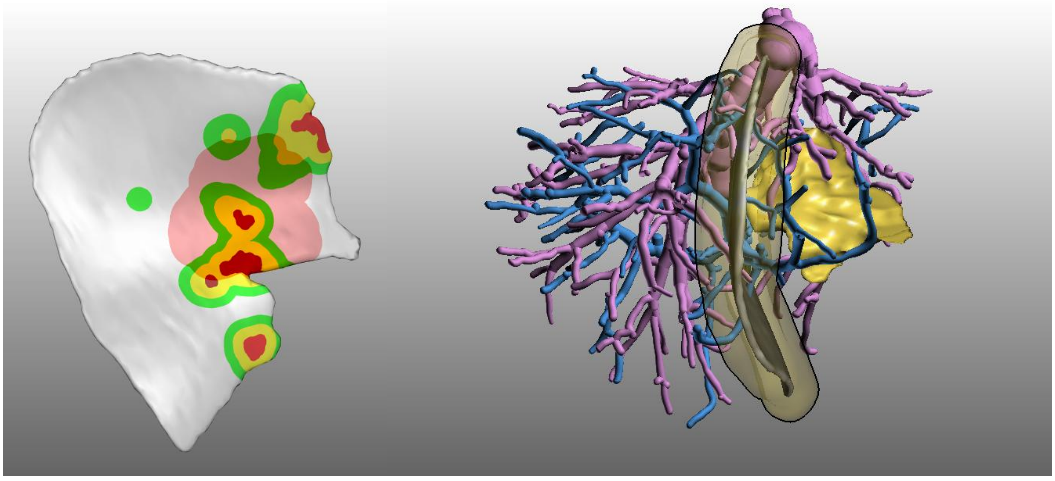
The routine in the operating room was taken into account when designing the auditory display. First, the sonic environments inside typical operating rooms were analyzed so that the system would not interfere acoustically with other signals in the room, enhancing detectability and discriminability. Second, sounds were chosen for the system that embody direct, representational metaphors of the instrument entering and exiting safety margins. Third, the sounds are only triggered at relevant moments, reducing user annoyance and thus enhancing acceptance and usability.

Results

Discussions with our surgical partners have indicated that an auditory display for surgical tools would be a welcome addition to the intraoperative system. Preliminary evaluations on liver phantoms suggest that the addition of auditory display does enhance recognition of uniform safety margins, thereby reducing dependence on the video monitor for clues about the instrument's distance to risk structures. In combination with the visualization of risk maps, the auditory feedback may prevent a possible damage to risk structures. Furthermore, several sound configurations have been produced, allowing for an in-depth evaluation of the design choices and modes of interaction.

Conclusions

As a rarely used modality in surgical navigation, audio shows increasing promise for computer-assisted surgery. Auditory display reduces the dependency on visual presentations, freeing the surgeon to focus his or her attention on the situs rather than on a video monitor. Our auditory display for image-guided liver surgery warns more clearly of risk structures, making them easier to identify and avoid, thus allowing the surgeon to more safely and efficiently follow a resection plan. The surgeon needs to divert less attention to the video monitor during the surgical procedure, only referencing the video monitor when notified by the auditory display. Although our system improves the recognition of safety margins being entered or exited, further evaluations are necessary to minimize undesired emissions of sound, improve the intelligibility of the tones, create sounds that are aesthetically pleasing to the surgeon, and further enhance the system's usability in the operating room. Furthermore, registration error must be considered and compensated in the auditory display.



(a) (b)

Fig 1: (a) Risk map with shadow-like distance indicators that encode different safety margins around important vessels (dark red: 2 mm, yellow: 4 mm, green: 6 mm),. The light red area encodes the proximity (10 mm) to a tumor. (b) Coronal view of the resection proposal, including hepatic vein (purple), portal vein (blue), tumor (yellow) and the safety margin around the planned resection surface (dark yellow).