A Strategy to Improve Information Display in Navigated Surgery

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Abstract:

Image-guided surgery is daily business in many hospitals nowadays. Pre-operative data and navigation systems provide different views to the task at hand, but as they are displayed on monitors surgeons need to integrate several spatial frames of reference in order to map the displayed data to the patient, which is a demanding task. Qualitative spatio-temporal representation and reasoning (QSTR) is a subfield of Artficial Intelligence which explicitly deals with formal abstract models of spatial knowledge. Based on our expertise in QSTR we argue for the integration of QSTR approaches to reduce cognitive load of surgeons regarding visual information display.

Keywords: information display, intra-operative information, qualitative spatial reasoning

1 Problem: Surgical Tasks and Visualization

One goal of modern surgery is to be minimally invasive, i.e., to induce minimal trauma to skin and soft tissue of patients. Image-guided or navigated surgery is a good means for pursuing this goal. As a consequence parts of the process are not directly visually observable as the target structure is hidden within the body of the patient. Nevertheless, based on preoperatively recorded data an optimal strategy can be planned to reach the target with a surgical tool. Then, during the surgery the surgeon has to follow preplanned steps, instructions, or paths. At this point we assume that first, intra-operative data is available, i.e., positions of patient and tools are known, and second, preoperative and intra-operative position data is aligned in an optimal manner. We are aware that this may be problematic, e.g., due to different orientation of the patient before and during operation tissue may be deformed significantly.

Two typical tasks in this context are ablation or resection procedures. Simplified, an ablation is a *pointing task*, e.g., placing a needle-like tool at a specific position in order to ablate the surrounding tissue, whereas a resection procedure is a *path following task*, e.g., in order to remove some organ part. In both cases the target position(s) are not directly visually perceivable by the surgeon. Current techniques use external monitors positioned somewhere in the operating room, which display a model of the region of interest together with the tool applied, e.g., [1]

In many cases a rich rotated 3D model is shown on the screen in order to provide as much information as possible. The monitor can be positioned with some degrees of freedom. However, in most cases the surgeon is not able to perceive patient, tool, and monitor without moving her head. Furthermore, the 3D model can be rotated arbitrarily. Under regular conditions a surgeon has no time to adjust the view while operating. So, a fixed view can be assumed, which is most likely not optimal in all stages during a process. Therefore, the surgeon has to perform the rather complex task of integrating several *spatial frames of reference* (FoR) [4] in the presence of head motion w.r.t. the patient, the tool, the external monitor, and the rotation of the model on the monitor. Our understanding of spatial frames of reference is based on findings in cognitive linguistics. According to [5] (see also for further details): a verbal utterance is based on three roles: a 'locatum' (entity currently described), a 'relatum' (entity in relation to which locatum is described), and an optional vantage (any entity which induces a direction), which is needed for projective directions, e.g. left or in front. A vantage is not necessary, if cardinal directions are used (north, east, ...). Each of these roles can be filled by speaker (first person), addressee (second person), or some other participant (third person). Categorizing the perceptions of a surgeon based on this schema reveals how complex the integration of the FoR is and why this can be a source of mistakes.

As QSTR explicitly deals with the formalization of such knowledge in cognitively adequate ways we argue for the application of methods from QSTR in order to simplify presentation and improve interaction with spatial data in intra-operative contexts.

2 Methods: Qualitative Spatio-Temporal Representations

Qualitative Spatio-Temporal Representation and Reasoning (QSTR) is a research field in Artificial Intelligence which neglects detailed, i.e., numerical data, and relies on limited sets of (spatial) categories. This comprises terms like left or right (relative orientation), north,east, etc. (absolute orientation), far or close (distance), and inside or overlapping (topology). Each term, in QSTR called relation, summarizes configurations which are indistinguishable w.r.t. the task at hand (also considered as commonsense knowledge). As in QSTR the relations need to have a well defined semantics, relations can be derived from numerical data. Furthermore, with relations reasoning can be performed on a logical level, e.g., finding data inconsistencies or how a situation at hand might evolve in the near future. For further details on QSTR we refer to [2].

3 Discussion: How to Improve Information Presentation

In commercial products a dominant strategy to simplify navigation tasks is to add a crosshair w.r.t. the puncture. The tip and shaft of the ablation needle are represented as circles and need to be brought into an overlap with the crosshair's center [1]. This reduces the 3D problem to a 2D problem (adjusting the circles) and a 1D problem (needle insertion), which improves surgeon's performance significantly. Nevertheless, surgeons still have to shift focus between patient/tool and monitor. Furthermore, the crosshair's orientation is aligned with the coordinate system of the patient. If a surgeon is not optimally aligned to the patient's body axes, which seems to be the regular case, reference frames for tool manipulation are distorted, e.g., moving a tool to the right results in a diagonal motion w.r.t. the crosshair. Strategies to reduce the need for visual feedback at all researchers, e.g., experiment with haptic or auditory guidance [1]. Nevertheless, experiments showed that these kinds of information presentation have its limitations and visual feedback is still desired by surgeons. Whereas performance in pointing tasks is promising, performance in path following is rather poor.

We gained the impression that in medical image presentation there is a tendency to rampant use of colors. In contrast, Hegarty exemplifies that highlighting certain aspects might improve information perception significantly [3]. Additionally, many young surgeons are very good at handling tools w.r.t. a 2D image, e.g., in laparoscopic interventions[1]. Discussions revealed the question whether display of detailed 3D models is really necessary during a surgical process. The advantage for surgery planning is beyond question.

4 Conclusion

Encouraged by our experiences with application of QSTR in domains like sea navigation, architecture, or robot control, and the considerations of people like Hegarthy, we argue for the application of QSTR approaches in the surgical context. For us the most obvious application is finding optimal views of a displayed model for the current situation, e.g., minimal object occlusion or optimal alignment of reference frames. Based on these approaches we hope that visual (and potentially auditory) information presentation can be optimized, e.g., w.r.t. number of displayed structures, number of focus shifts between patient and monitor, finding optimal angles of 3D model presentations, or finding most reasonable 2D projections for the stage a surgery is currently in. For this, we currently integrate the qualitative spatial reasoning toolbox SparQ[2] into the medical image processing and visualization software MeVisLab[3].

5 References

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[1] Based on interviews we assume that this is due to the (extensive) use of game consoles.
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[3] www.mevislab.de