An evaluation of image overlay projection guidance for liver tumour targeting

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Abstract:

The precision at which metastases of the liver can be targeted and ablated has been shown to significantly affect the rate of recurrence. Augmented reality guidance has the potential to remove error pertaining to the display of image guidance away from the direct view of the patient on a nearby monitor. We have proposed a projection overlay system that allows 2D guidance data to be viewed directly on the surface of the liver. The visualisation approach, which incorporates alignment and depth information, was evaluated in a phantom study on porcine liver tissue. An ablation needle was successfully inserted into 98% of 88 targeted virtual tumours in an average time of 21 seconds.

Key Words: Augmented Reality, Liver tumour ablation, Evaluation, Projection

1 Problem

The precision at which metastases of the liver can be targeted and ablated has been shown to significantly affect the rate of recurrence [1]. Image guidance techniques, based on preoperative image data, have aimed to increase precision by presenting visual feedback pertaining to the pose of surgical tools and the relative positions of underlying structures, on nearby monitors [2, 3]. The removal of the visual data from the direct surgical scene, has however, been reported to be suboptimal due to a lack of intuitiveness and the need for sight diversion [4, 5]. In [4], Hansen et al. concluded that mental fusion of planning models with the current surgical view was error-prone and that it frequently resulted in distracting comparisons during the intervention that consumed an unacceptable amount of time. Augmented reality (AR) projection techniques described by Sugimoto et al [5] and Gavaghan et al [6] allow underlying anatomical structures to be viewed directly on the surface of the patient. The techniques improve intuitiveness and allow the surgeons focus to remain on the patient, but accuracy pertaining to the perceived position of underlying structures was reduced due to the introduction of parallax error. In previous work, a 2D guidance application which is inherently unaffected by the users line of sight was developed in order to allow hidden structures to be targeted more accurately using projection AR during open liver surgery [7]. Within this work, we evaluate the usability of the targeting guidance visualisation by determining the accuracy and time required to locate hidden virtual targets within a liver phantom.

2 Methods

The targeting visualisation, described in detail in [7], was designed to guide a tracked ablation needle to a selected target object. A cross hair target is displayed on the surface of the liver on the ablation needle axis (refer to Fig 1.). A smaller circle aids in the alignment of the needle shaft along the trajectory from the tool tip to the target and a depth bar indicates the distance remaining to the target.

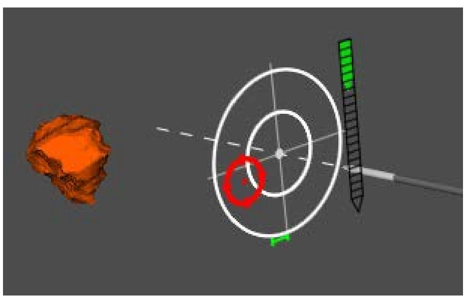
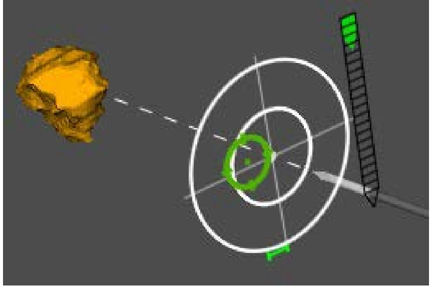
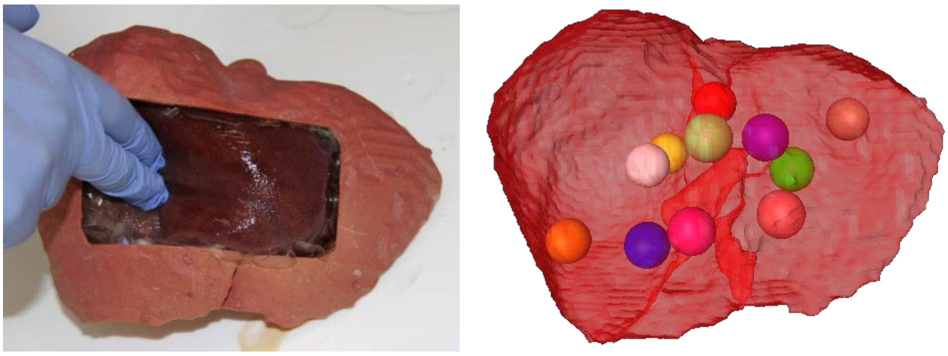


Fig. 1: Guidance data with unaligned needle shaft (left) aligned needle (centre) and the projection device (right)



The usefulness and effectiveness of the guidance projection in assisting in the location of non-visible internal targets, was quantitatively assessed in experiments on porcine liver tissue.



The optically tracked, portable image overlay device described in [6] (refer to Fig. 1.) was integrated into a commercially available image guidance system for open liver surgery [8]. A virtual model of a human liver surface was segmented from patient CT data by MeVis distant services, Germany. A portion of the anterior liver surface was removed and the remaining surface was physically constructed using rapid prototyping 3D printing. The rigid phantom shell was lined internally with a sterile drape and filled with porcine liver tissue (refer to Fig. 2). The liver model was augmented with eleven spherical virtual targets with 2 cm diameter (refer to Fig. 2). The phantom was secured to a metal plate and positioned on a surgical table within the workspace of the navigation system‘s optical tracking sensor.

Fig. 2: Rigid liver phantom with porcine liver tissue (left) and virtual liver model and 11 spherical targets (right).

Eight medically untrained subjects (5 male and 3 female) all familiar with image guidance techniques, were selected for testing. Subjects were required to position the tip of a needle within each of the virtual targets using only the projected guidance target (refer to Fig. 3). Only one tumour was activated for targeting at any one time. The display of the target tumour model was deactivated to avoid perception confusion caused by parallax error. Subjects were given a two minute training period immediately prior to testing and were offered an assistant to hold the projection device. Prior to each test, the ablation needle was calibrated and additionally used to register the liver to the virtual model via the pair point matching processes described in [1] .

The position of the optically tracked ablation needle was recorded throughout the targeting of each landmark and the targeted position (as decided by the user) was recorded. The tracked needle path and target positions were later plotted with 3D anatomical models in Amira® (Visage Imaging, USA). Target positions located within the volume of the target tumours were defined as successfully reached. The tracked tool position, rather than the absolute tool position was acq-

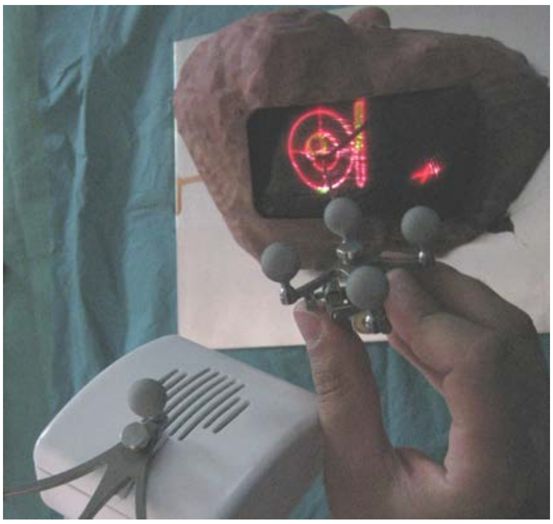
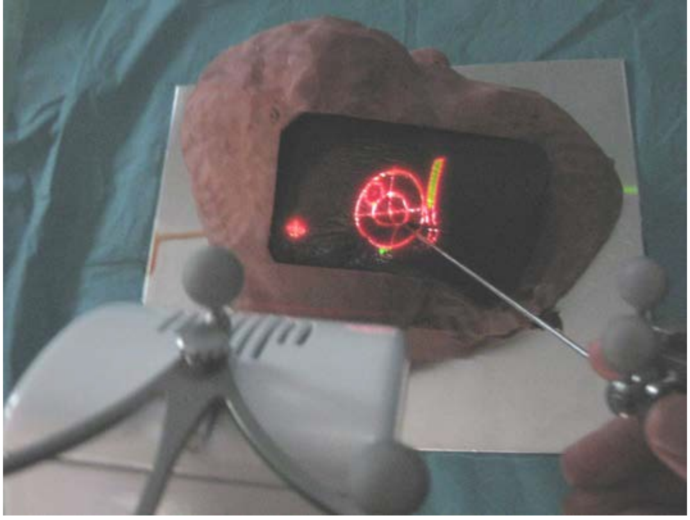


Fig. 3: Projected targeting guidance (with cross hair, alignment circle and depth bar) displayed on the surface of the porcine liver phantom under the tip of the optically tracked ablation needle during the evaluation.



uired in order to observe error due the visualisation method alone. Whilst error in tool marker tracking (approximately 0.3 mm) could not be eliminated, error due to tool calibration and patient registration were removed from measurements.

3 Results

Using the described augmented reality target guidance approach, the ablation needle was successfully inserted into 86 of the 88 targeted tumours. Six of the eight subjects successfully inserted the needle into all eleven tumours. The needle tip missed the targeted tumour by 7.2 mm and 6.9 mm in the two unsuccessful insertions. All insertions were performed in less than one minute with the average time for needle insertion being 21 seconds. A summary of the evaluation results is displayed in Table 1. An image of the tool path and final target positions for a case in which all targets were reached is displayed in Fig. 4.

Table 1: Targeting accuracy results summary.

N	Targeting Time	Accuracy	Missed distance (mean)
88	21 s	97.7 %	7.0 mm

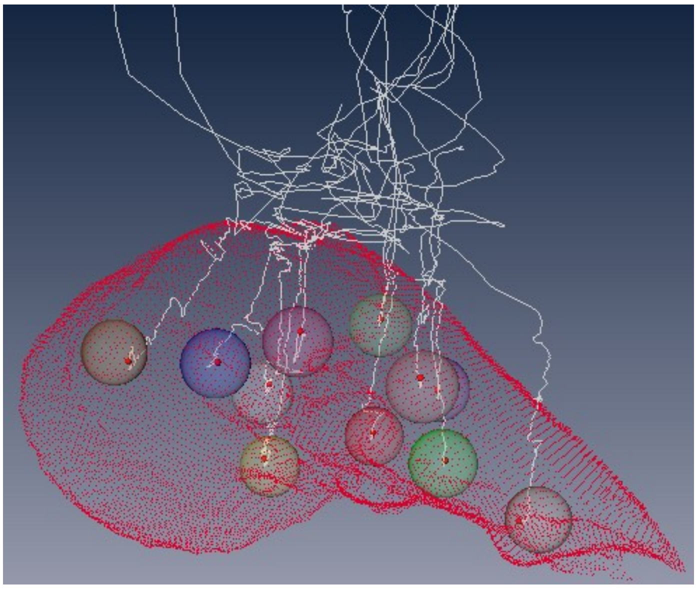


Fig. 4: The ablation needle paths and target positions for all eleven tumours from a subject who successfully targeted all tumours.

4 Discussion

Within this work, we have presented a quantitative analysis of the effectiveness of a novel system for augmented reality guidance of liver tumour ablation. The described approach allows underlying tumours to be targeted without the need for sight diversion from the patient to imaging data displayed on an additional monitor. Additionally, the approach reduces the required level of hand eye coordination by displaying all guidance data in the coordinate system of the patient. Whilst projection remains a 2D visualization method, perception of depth was aided by the use of a depth indicator bar. The high percentage of successfully targeted tumours by untrained users demonstrated the effectiveness of both the orientation and depth guidance.
Users were able to locate the coarse position of the tumour by moving the needle (held approximately perpendicular to the liver surface) just above the liver surface until the small guidance circle turned green. The user could then align the

needle such that the small circle was cantered in the cross hair target and then penetrate the liver tissue until the indicat-

ed depth. As the needle was correctly aligned before penetration, little correction to the trajectory was required once the needle was within the liver tissue (refer to Fig. 4).

Penetration of the liver tissue by the needle resulted in significant deformation to the liver surface causing the projected image to also distort. However, as the targeting guidance does not rely on being displayed in a geometrically correct position, this phenomenon did not significantly diminish the effectiveness of the guidance. The guidance data was designed to be viewed on a surface area of approximately 5cm x 4cm with the projection device held at an optimal distance of approximately 30 cm from the patient. The size of the image can however, be easily adjusted by moving the device closer or further away from the liver surface. No problems pertaining to image size were observed during these experiments.

Line of sight remains a challenge for all navigation systems relying on optical tracking. Previous usability studies however, showed that the portability of the device greatly minimized the problem of line of sight because the device could be quickly and easily moved back into the workspace without disrupting the surgical procedure [9]. This effect was again observed during these experiments and the need for line of sight did not inhibit the user in a significant way.

A high percentage of tumours successfully targeted in this study indicates that the described approach may improve targeting precision which, in turn, may result in more successful treatment. However, whilst results of this experiment are promising, the evaluation is limited to the effectiveness of the guidance visualisation. Error due to the registration of a soft tissue organ was emitted from the evaluation via the use of virtual targets. Whilst rigid registration has been shown to be sufficient for local regions of the liver [10] additional verification of the targeting of internal structures in clinical cases is required before the overall accuracy of the approach can be known. Error resulting from image-to-patient registration, tool calibration and system error may be checked intra-operatively by projecting the liver surface and by projecting tracked tools of known geometry back onto themselves. Additional methods of intra-operative verification including verification of the trajectory will be the subject of future work.

5 References

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