A Real-time Simulation, Guidance and Visualisation Platform for Intra-operative Minimally Invasive Robotic Surgery

Andrew W Dowsey, Philip Pratt, Marco Visentini-Scarzanella, Johannes Totz, Mirna Lerotic, Danail Stoyanov and Guang-Zhong Yang
Institute of Biomedical Engineering, Imperial College London, UK - http://vip.doc.ic.ac.uk/gpu

INTRODUCTION

Robotic devices represent one of the most promising enhancements in modern operating theatres for minimally invasive surgery (MIS). They facilitate the performance of complex MIS procedures by using microprocessors to control the surgical instruments and improve the ergonomics in the operating theatre using a master-slave configuration (Figure 1). Surgical robotics provides a unique platform for enhanced intra-operative visualisation, navigation, adaptive control and the development of more repeatable and effective surgical procedures.

In this poster, we present a platform for pre-operative surgical simulation and processing together with visualisation and modelling of patient-specific data during surgery. In this setting, GPU acceleration is essential to achieve reliable real-time performance. We discuss our research and the hardware and software challenges for providing a full GPU-based end-to-end solution that can be translated to clinical practice.

METHODS

For enhanced visualisation, navigation and adaptive control, the surgical robot platform must process a vast amount of multi-modal patient-specific data in real-time. This involves the fusion of pre-operative medical imaging data and biomechanical models with the intra-operative video in order to visualise the surgical site.

PRE-OPERATIVE SURGICAL SIMULATION (FIGURE 2)

For surgical planning and rehearsal, we have developed patient-specific appearance models derived purely from patient data for the generation of photorealistic pre-operative subject-specific visualisations [1]. The methods employed include direct volume rendering using ray-casting, subsequent integration with surface meshes for multi-modal visualisation, and deferred shading for high quality custom patient-specific shading models. We provide a technique for the estimation of the Bidirectional Reflectance Distribution Function (BRDF) of patient tissue [2], which is non-trivial as there is almost no control over lighting conditions and choices of viewpoint.

SOFT TISSUE TRACKING (FIGURE 3)

With the emergence of stereo-laparoscopes, the video signal from the operating site can be used to recover the 3D tissue structure and morphology *in-vivo* [3]. This process is computationally demanding and in [4] we present a novel GPU-accelerated affine-invariant multi-scale corner detector based on anisotropic features to cater for these difficulties. The CUDA implementation realises a speedup of 62-88x on a NVIDIA GeForce GTX280. The technique can be used to propagate a dense 3D reconstruction and to track temporal motion of the soft-tissue.

IMAGE GUIDANCE (FIGURE 4)

Fusion of pre-operative medical imaging data requires online biomechanical modelling of the tissue motion extracted in the tracking phase. We have developed a finite element simulation of soft tissue deformation in CUDA, which enables nonlinear registration at interactive frame rates at the highest levels of overlay accuracy [5]. The framework is driven by 3D measurements made in the video stream to cater for rhythmic tissue motions arising from respiration and the cardiac cycle.

Figure 1. The daVinci Surgical System (Intuitive Surgical, Sunnyvale, CA) at the Institute of Biomedical Engineering. Imperial College London.

AUGMENTED REALITY (FIGURE 4)

Novel surgical robots provide visualization platforms that enable stereo vision. Introducing model overlays in such environments can lead to inaccurate depth perception of the displayed model. A pq-space augmented reality technique [6] ensures the deformable models are embedded within the surgical scene with realistic depth cues, as shown in Figure 4. The method is based on shape from shading information from the real-time video to provide semi-transparent salient features that occlude the virtual model and aid perception.

CONCLUSION

The future of navigation and control in advanced robotic-assisted MIS is in the intelligent use of pre-operative and intra-operative patient-specific data. This requires real-time processing and visualisation of multiple HD video streams for fusion with high-resolution 4D biomechanical models and medical imaging data, therefore realising interactive augmented-reality and human-machine interfacing with the surgeon. The main roles of GPU technology in this context can be summarised as:

- Real-time processing of multiple high speed HD video;
- In vivo fusion of intra-operative and pre-operative medical imaging data and biomechanical models; and
- Minimal latency between video acquisition and augmented reality visualisation to support real-time image-guidance.

The creation of a next generation image-guided medical robotics platform through cross-disciplinary research and with the use of GPU technology will help transform the future of surgery.

REFERENCES

[1] J. Totz et al, Patient-specific Texture Blending..., MICCAI (AMI-ARCS) 2009
[2] A. Chung et al, Patient-specific Bronchoscopy..., IEEE TMI, 25:503-13, 2006
[3] D. Stoyanov et al, Intra-operative Visualizations..., IEEE/OSA JDT 2009
[4] S. Giannarou et al, Affine-Invariant Anisotropic Detector..., ISBI 2009
[5] P. Pratt et al, Image Guidance and Surgery Simulation..., ISBMS 2008
[6] M. Lerotic et al, pq-space Based Non-Photorealistic..., MICCAI 2007

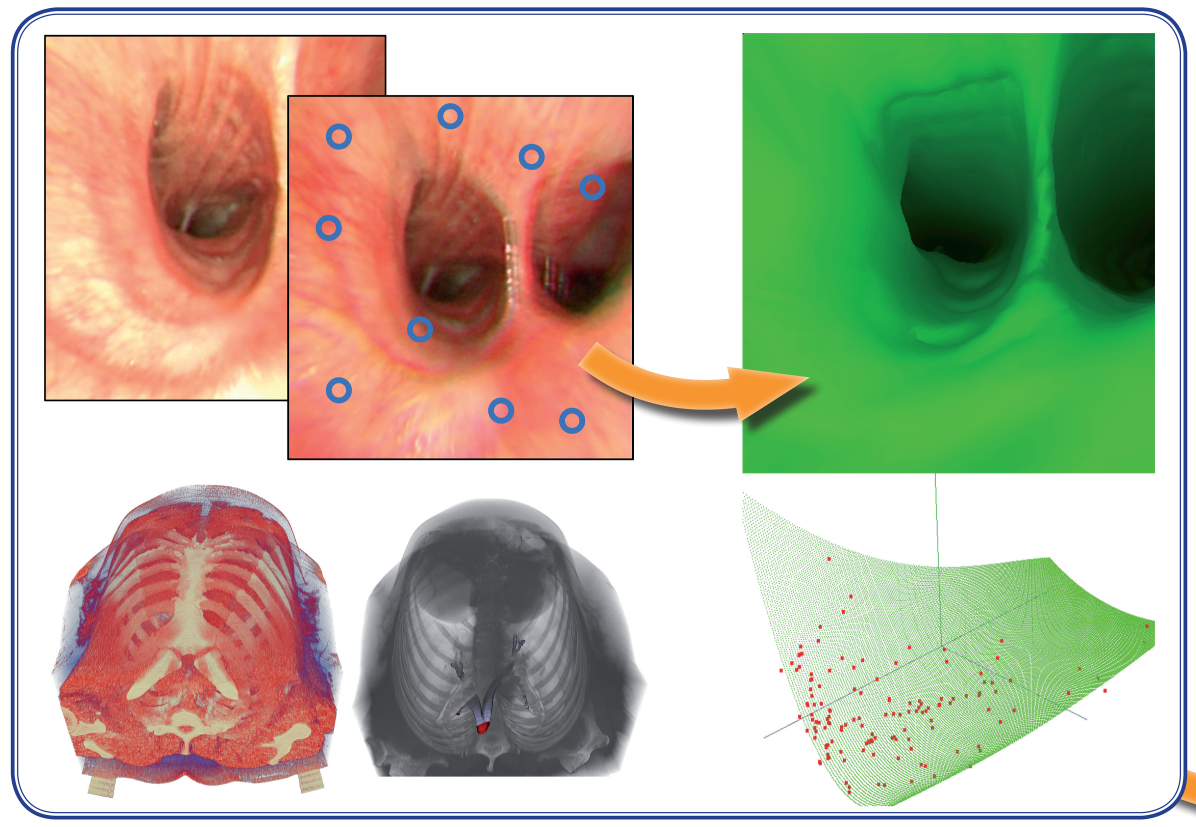

Figure 2. Intra-operative video (top-left) and pre-operative CT (bottom-left) allows modelling organ appearance in real-time. The video is analysed to estimate the tissue's BRDF (right). This becomes a powerful tool for pre-operative training and rehearsal.

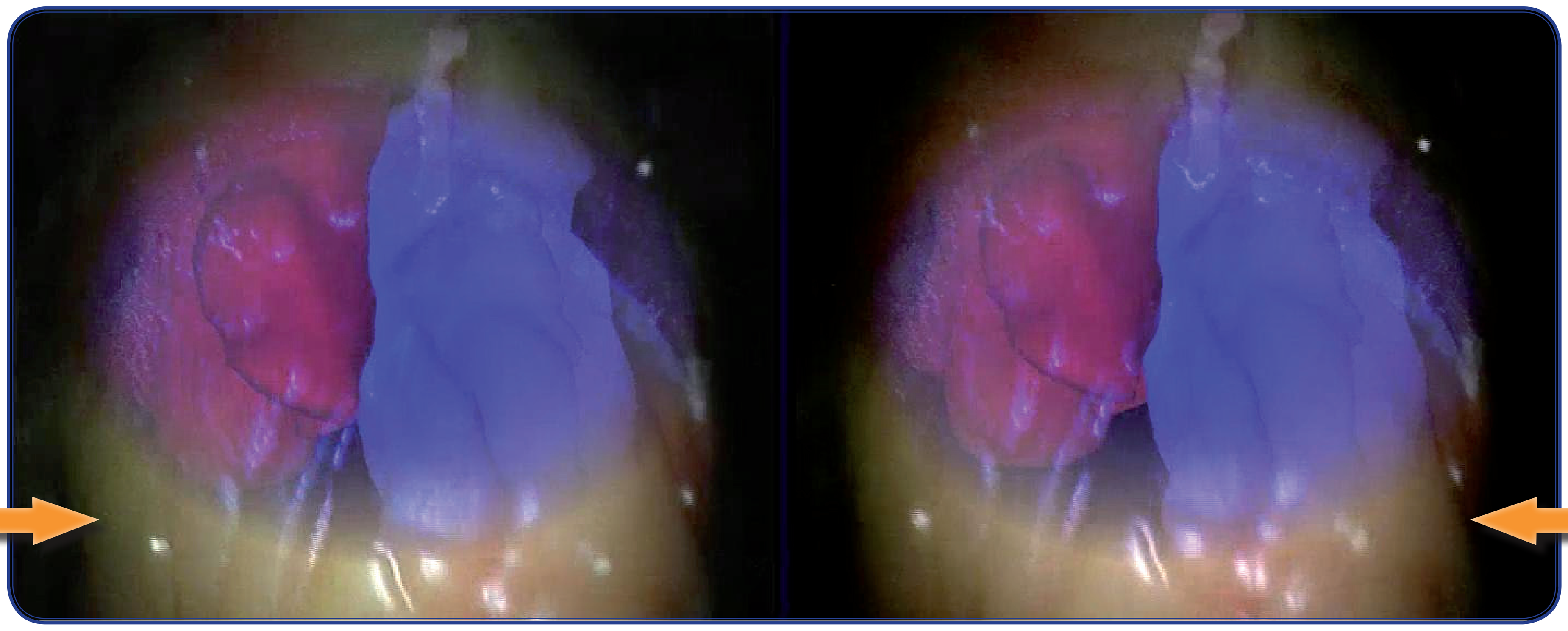

Figure 4. Real-time stereoscopic overlay of intra-operative video with preoperative dynamic CT data using a phantom heart model.

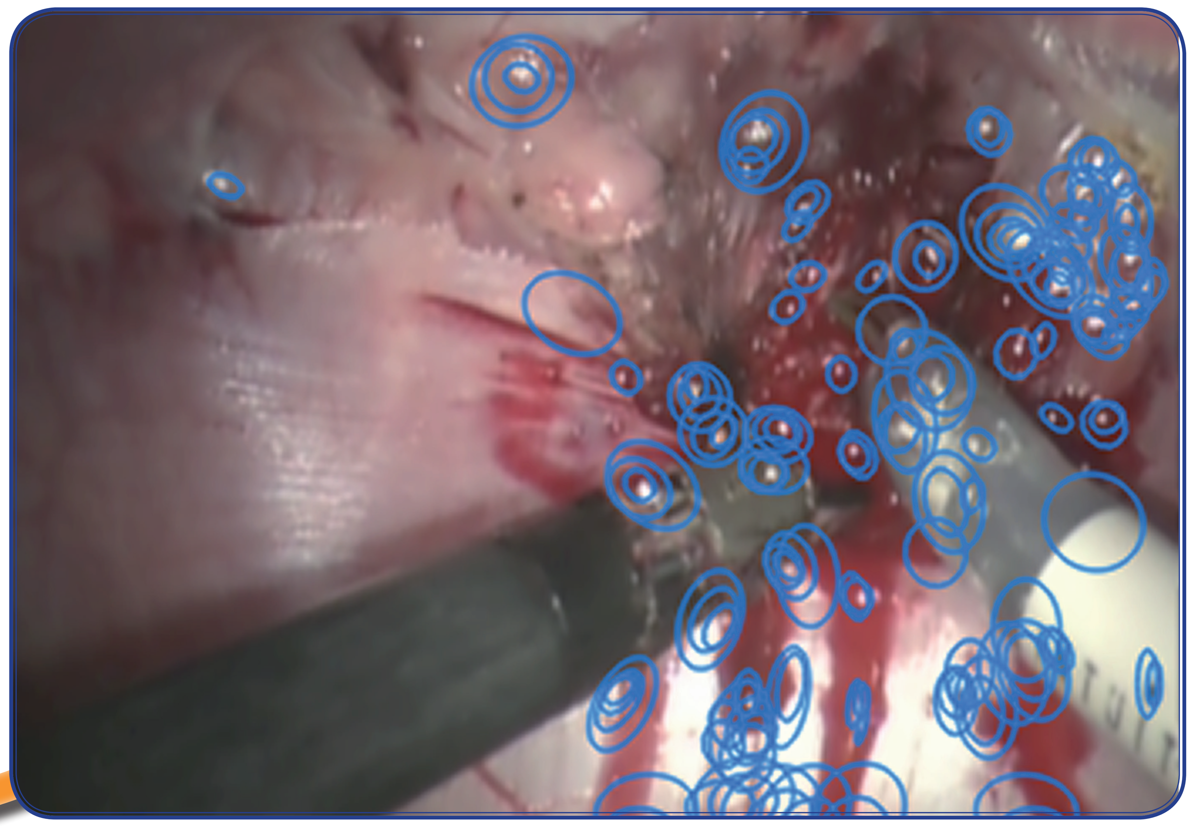

Figure 3. Multiscale anisotropic feature tracking during laparoscopic cauterisation. The radius and orientation of each ellipse indicate the scale and directional components of each detected corner.