Development, Validation, and Modelling of Image Guidance Systems for Surgery

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Introduction

Image guidance systems for surgery enable the surgeon to make use of information from various sources during surgery. Such systems have the potential to improve outcomes for patients by allowing the surgeon to easily assimilate prior knowledge from pre-operative clinical scans as well as novel intra-operative imaging techniques. A key challenge is how to filter and process this information to allow it to be presented in an accurate, timely, and intuitive manner. Badly designed or poorly understood image guidance systems risk distracting the surgeon with irrelevant or incorrect information, leading to patient harm.

The aim of my research is to develop tools to better quantify the performance of surgical image guidance systems, and measure how the system performance affects patient outcomes. I will present the results of my work developing the “SmartLiver”[1] image guidance system for minimally invasive liver surgery. I will follow this with a proposal for a generalised model of image guidance systems as multi input control systems.

Methods

The SmartLiver image guided surgery system combines inputs from pre-operative CT scans, optical and electro magnetic tracking systems, computer vision, and intra-operative ultrasound to provide the surgeon with an intuitive visualisation of blood vessels and liver tumours during minimally invasive liver surgery. The system has been developed over three years and is currently undergoing human trials at the Royal Free Hospital.

To enable further development of the system, I propose a generalised model of image guidance systems as multi input control systems, where the inputs represent signals from the clinical environment, and the outputs are either a visualisation for the surgeon or control signals for semi-autonomous surgical robots. At the core of the system are a set of state vectors that maintain the estimated physical state of the relevant surgical components, see Figure 1. Modelling the system in this way enables the use of methods from control theory and artificial intelligence research to be used to improve system accuracy.

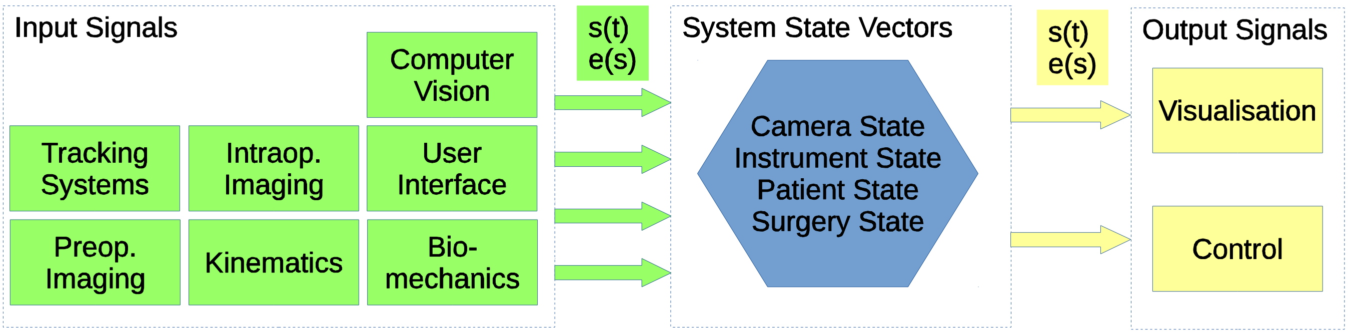

Figure 1: Modelling an image guidance system as a multi input control system. Time varying input signals, (green, s with signal dependent errors e) are used to estimate the state of patient and clinical instruments (blue), informing the surgeon via visualisation or control signals (yellow).

Results

In-vivo validation shows that the system can currently locate anatomy with an accuracy of 15mm. Significant contributions to system error are the difficulty in imaging the intra-operative liver surface and organ motion. We have proposed a development plan to address these issues to improve the accuracy to 3 mm [1].

Discussion

Current image guidance systems do not combine information from disparate sources in an optimal way. By proposing a novel system model together with intelligent estimates of the input signal errors, we have the potential to develop the next generation of intelligent image guidance systems.

Funded by: The SmartLiver project is funded by the Wellcome Trust and Department of Health, HICF-T4-317.

References

[1] Thompson et al, 2015, “Accuracy validation of an image guided laparoscopy system for liver resection”, Proc. SPIE Medical Imaging, 9415, pp 941509-941509-12.