Developing a Next Generation Colonoscopy Simulator
A white paper from the CSIRO Biomedical Imaging Team.
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Introduction

In Australia, colorectal cancer is the most commonly reported cancer affecting both men and women. It is the third most common cause of cancer related deaths with an increasing risk profile from age 43 onwards. Current rates indicate that one in 22 Australians will develop colorectal cancer within their lifetime, one of the highest rates in the world.¹

Unfortunately few, if any symptoms are exhibited until the cancer has reached a relatively advanced stage, but treatment and survival rates improve significantly with early detection. Steps have been taken by the Department of Health and Ageing to trial programs for early detection. The Australian National Bowel Cancer Screening program² is currently offering faecal occult blood tests (FOBT) to Australians turning 55 or 65 years of age between 1 May 2006 and 30 June 2008, with positive FOBT results usually referred for a colonoscopy.

Colonoscopy is regarded as the optimal examination for the detection and removal of precancerous colonic polyps (Figure 1) and also allows identification, and histological confirmation through biopsy. Unfortunately, colonoscopy is a difficult procedure to master with most training occurring on real patients. Studies have shown an increased frequency of minor adverse effects associated with trainee procedures and a direct correlation between adverse effects and patient reluctance to attend follow-up examinations has been shown. Training costs for gastroenterology fellows are high due to a reliance on high fidelity training settings and the longer procedure times associated with trainee procedures.⁴
Provision of simulators for training surgical procedures has many benefits including reduced risk to patients, reduced training costs, ability to train difficult and rare pathologies and the potential for off-patient certification. Unfortunately, existing colonoscopy simulators rate fairly low for haptic and anatomical realism and do not provide a case variety with a level of difficulty to make them useful for anything but novice training.5

What is CSIRO doing to help?

As a project of the Preventative Health National Research Flagship, CSIRO is developing the next generation colonoscopy simulator that aims to address the deficiencies in existing simulators by improving dramatically: case complexity, anatomic complexity and realism, visual and haptic realism. A planned collaboration with the Queensland Health Skills Development Centre and the University of Queensland School of Human Movements Studies around development of the Fundamentals of Colonoscopy training curriculum, as well as with leading experts in the field of Gastroenterology, has the project well positioned to provide a platform that is relevant for off-patient training needs within Australia.

Our long term goal is to provide a metrics based training and skill evaluation system that is not only useful for trainee instruction but can be leveraged for skills maintenance and eventual certification.

Novel Haptic Interface

In collaboration with CSIRO, Ecole Polytechnique Fédérale de Lausanne (EPFL) has developed a novel haptic device6 (Figure 2) which allows insertion of a modified Olympus colonoscope7 and provides torsional and translational force feedback to the user. The novel design of the device allows motion in one direction while impeding the other and features an unlimited rotational and translational workspace. The device fully supports endoscope insertion and removal.

Figure 2: Our colonoscopy haptic device (a) The device has the novel ability to provide motion in one direction while impeding the other (b) An instrumented Olympus Colonoscope is inserted into the haptic device.
Extraction of Simulation Data from Patient CT Scans

Existing colonoscopy simulators rate poorly for anatomical realism which is why the focus of our initial research tackled the extraction of simulation data from patient abdominal CT scans (Figure 3). Our advanced processing techniques extract the colonic lumen from a database of actual CT scans and generate surface meshes, centreline splines and texture coordinates required for real-time simulation.

![Patient CT scan and extracted colonic surface](image)

Figure 3: Patient CT scans are processed to extract the colonic lumen (a) A patient CT scan (b) The extracted colonic surface.

Highly realistic rendering environment

Harnessing the processing power of the modern Graphics Processing Units (GPU) our researchers have devised novel techniques for rendering highly realistic colonic lumen surfaces (Figure 4).

Our real-time OpenGL rendering framework uses GLSL shaders to provide per-pixel lighting and texturing effects and accurately models the lighting environment at the endoscope tip as well lens distortion and soft shadows. To faithfully reproduce the colonic lumen and various surface pathologies, multi-texturing techniques including normal mapping are employed.

To facilitate smooth and realistic surface deformations, a mapping of the underlying physical model to the high resolution surface mesh is performed in real-time on the GPU.

Videos are available from: [http://aehrc.com/biomedical_imaging/colonoscopy.html](http://aehrc.com/biomedical_imaging/colonoscopy.html)
Advanced Physical Modelling

Research into techniques for physically based modelling of the colonic lumen and surrounding tissues has resulted in a novel non-linear constitutive model for soft tissue deformation which we solve in real-time on the GPU. This Total Lagrangian Explicit Dynamic (TLED) solver\textsuperscript{10} supports highly accurate real-time modelling of soft tissues using either tetrahedral or hexahedral elements. A mass-spring surface model with support for dynamic insufflation effects and real-time collision detection has also been developed.

Accurate modelling of the endoscope and its interaction with the colon is achieved through a beam model where the endoscope is decomposed into a large number of flexible units. Collision detection of physical models running on the GPU is enabled through a high performance GPU spatial hashing implementation which operates on data stored in graphics card memory and alleviates the time consuming transfer of data between CPU and GPU.

Figure 5: Our real-time TLED GPU solver computes non-linear soft tissue deformations including viscoelasticity and anisotropy. This figure shows the viscoelastic response of a cube under compression, demonstrating relaxation over time (colour map is element stress).
Figure 6: We have developed an advanced physical model editor which allows us to represent the colonic surface as efficiently as possible (a) External view (b) Internal view with editor toolbar.

Figure 7: A beam model of the endoscope accurately represents the physical properties of the endoscope.

Simulation Framework

The project has developed a complete, modular framework\textsuperscript{11} (Figure 8) for surgical simulation in C++, capable of running complex simulation scenes at frequencies of up to 1000 Hz. The framework is highly configurable and allows development of new components through a plug-in architecture.

Clinical Case Design

To fulfil current and future training and certification requirements, we are developing a database with clinical cases which will allow us to generate any arbitrary case based on criteria for difficulty, pathology, bowel preparation level and other pertinent factors. Using ranged variables with randomisation, this unique database aims to provide an effectively infinite number of different cases for training and certification.
Figure 8: Our modular simulation framework allows integration of many components at haptic rates (1000 Hz).

Further information contact us

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References


