White Rose
Health Innovation Partnership

TECHNOLOGY bulletin

Health Technology Bulletin: 3D Imaging, Modelling, and Visualisation

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White Rose HIP Health Technology Bulletins

The White Rose Health Innovation Partnership (WRHIP) aims to accelerate new health-related technologies by facilitating interactions between academia, industry and the NHS using an *open innovation* approach.

The new projects funded as part of this initiative are built upon a foundation of excellence in health innovation by the Partnership's members. This series of Health Technology Bulletins offer an introduction to this research excellence and cover a broad range of clinical and technology areas.

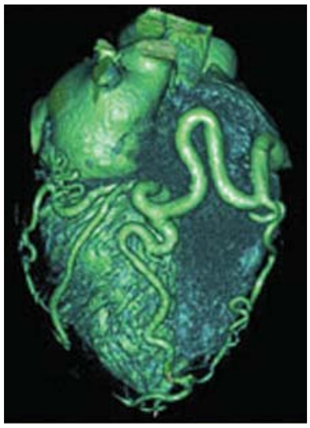
Each bulletin is written to give a general introduction to the topic area along with short case studies of clinical applications of new knowledge. Information is also presented on where to learn more about these new technologies and health challenges, and how to access the network of health innovation professionals established by the Partnership.

Technology Overview

3D Imaging, modelling, and visualisation technology is evolving rapidly. Along with the exponential growth in data storage and processing capabilities of desktop computers, other software and hardware options are becoming more sophisticated and less expensive, enabling clinicians and researchers to work in previously inconceivable ways. The existing technologies for capturing and interacting with 3D data are very exciting, and have applications that may have yet to be discovered. Here we will discuss some of the existing technologies in medical image processing and 3D data capture/ manipulation, provide an overview of the technologies being used at the University of Sheffield and investigate some of the emerging and potential applications of these projects to the healthcare sector.

Medical Imaging

MRI and CT scanners are constantly improving, providing unprecedented detail, speed, and patient comfort, leading to improved diagnoses. Utilising such innovations as upright open-sided MRI (Fonar®) and 4D cardiac scanning, clinicians can investigate a patient during an episode of pain or irregularity to better understand the cause and potential treatments. Used in conjunction with modelling and visualisation techniques, the possibilities for innovation are limitless.



Modelling and Visualisation

Commercially available software packages such as Mimics (Materialise), 3D-Doctor (Able), OsiriX (freeware) and Analyze (CNSoft) allow clinicians and researchers to interact with data obtained from the scanners in ways which had not been considered possible even a few years ago. Image data can be segmented into a myriad of structures and pathways, and 3D visualisations can be designed. Accurate measurements can be taken and make virtual cuts and other modifications to anatomical structures and medical devices.

3D models obtained from laser scanning or from medical imaging can be exported to desktop modelling software packages such as 3ds Max (Autodesk) for manipulation, resizing, animation, incorporation into more complex models and more. Not long ago, such software was virtually unknown outside of the movie and computer games industries, but now is exploding into applications in other areas, including healthcare.

Laser surface scanning

A largely underused technology which can be complementarily applied to traditional medical imaging is laser surface scanning. When paired with 3D modelling software, nearly any structure not located inside the human body can be recorded, manipulated, and altered within 3D space. There are numerous applications in which 3D surface scanning can be useful, a few of which include: recording surface anatomy for pre- and post-operative comparison and planning, scanning instruments or devices for reverse engineering or redesign, 3-dimensional databases of structures for use in morphological research, and for recording specimens for teaching purposes. 3D images can be used to examine fragile specimens that will not withstand repeated handling or for sharing with colleagues without the need for the presence of the patient. Data capture is non-contact and eliminates the need for creating casts and moulds when multiple copies of a specimen are needed; it can either be examined/measured virtually, or exact copies created on a 3D printer. Laser scanned models also make especially useful visual aids when presenting case studies, as they can often be more descriptive than 2D photographs.

There are many devices for surface scanning on the market, with instruments capable of accurately scanning detailed items to the sub-micron level from objects smaller than a human tooth to as large as buildings. These can be static scanners that are associated with a specific environment such as a lab (Cyberware), portable (Minolta, Perceptron), or even handheld scanners that can be contained in a briefcase (Polhemus FastSCAN). 3D laser scanners work by bending a beam of light over the surface of an object; the distortion of the beam as it passes over the object is captured by a camera and recorded in a coordinate system by associated software. The coordinate information is represented as a point cloud, the vertices of which are then triangulated into a mesh and surfaced, resulting in a 3D image of the object. Some devices have a limited capability to capture colour information, but most record only the shape of scanned objects. The infrared lasers used in most scanning devices are eye safe and have no known adverse effects on humans, making them ideal for use in medical settings. The 3D models created from laser scanned images can be measured and manipulated in 3D space, and the measurements exported to a variety of spreadsheet and statistical packages. Real-world measurements can be replicated along with the inclusion of novel measurements that would be impossible on an actual patient. For example, dimensions of a wound or the diameter of an eye would cause pain or discomfort to a living patient, but can be easily taken from a scan.

Case Studies

Prosthetics and surgical planning

Packages such as Mimics already allow for surgical simulation. It is a similar concept to flight simulator training for Air Force pilots. The trainee gets to experience real-life situations in a safe environment. Surgeons will have many hours of hands-on experience in a procedure before putting real patients at risk. Haptic feedback technology, which allows for the surgeon to "feel" virtual structures will also become more readily available and integrated within the surgical simulators within a period of years. Investigators from the Universities of Coventry and Sheffield and the Sheffield Teaching Hospitals Trust have been developing an affordable surgical knee arthroscopy training system (SKATS), which incorporates haptic feedback in a mixed reality environment. A recent study (Moody et al, 2008) found that the SKATS virtual training environment was a promising tool for surgical training.

3D models obtained from patient medical imaging data are revolutionising the way in which researchers and clinicians can interact with human data. Currently at the University of Sheffield, researchers in oral biomaterials are investigating novel methods of rapid prototyping of facial prosthetics to decrease the waiting time for patients with severe facial deformities, and to enable replacements to be generated quickly. Patients will be able to receive fitted prosthetics even as their faces change through successive surgeries. Surgeons can also use the 3D models to plan surgeries and create implants before entering theatre.

Cardiovascular research is another area in which significant advances are being made due to the use of visualisation and modelling techniques. The Academic Unit of Medical Physics is analysing arterial stents by simulating mechanics and flow in virtual space in an effort to reduce restenosis. Additionally, the unit is investigating methods for automated registration of generic aorta mesh models to patient imaging data to produce patient-specific models for use in blood-flow simulations and structure changes over time.

Medical education

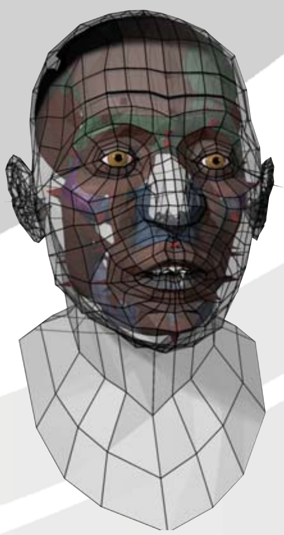
3D modelling can be used as the next step in biomedical illustration and medical education. Medical training programs are currently experiencing a shortage in cadaveric specimens for teaching purposes. This is due to a number of factors, including the rising costs of licensing for human tissues and dwindling numbers of body donors. The remaining donors are usually elderly and in poor health. The use of virtual remains for surgery simulation and anatomy/physiology teaching is likely to become a valuable teaching tool within a few short years as researchers seize upon the potential uses of existing technology.

For example, a model of the heart for use in teaching medical students can be produced from an actual patient by exporting CT scan data to a 3D modelling package. The various structures can be isolated, colour and texture applied, and an animation of the organ in motion produced in interactive 3D on a web-based interface. An entire body (of a cadaver or a living donor) can be scanned and visualised, allowing for repeated and detailed exploration of a number of systems; this is impossible during traditional dissection as once a structure has been cut, it cannot be revisited. Traditional dissection is a destructive and fleeting process: nerves and vessels are cut when the digestive system is examined, superficial muscles are often irreparably damaged when viewing the deep ones; once a structure has been dissected it us unavailable for later study, and access to the lab is usually limited to a very small window. Unusual morphologies or interesting conditions are not easily preserved for future classes due to the destruction and degradation of the specimens. Prosected specimens do not allow for close inspection of the structures and are by definition only part of the larger picture. In a 2007 article, Granger and Calleson suggest that dissection videos and peer-teaching do not fully compensate for a reduced dissection programme due to the lack of interaction with the material in the third dimension. Additionally, a 2004 study indicated that students accessing interactive computer materials (including cross-sectional materials) enhanced dissection teaching. These are important considerations as access to cadaver dissection is declining.

Using virtual remains can circumvent some of these issues as the 3D models can be available 24 hours a day and are non-destructive. Even tiny structures such as the nervous system can be preserved and explored repeatedly, remotely, and can be used by successive years. Donors can be representative of the entire population, spanning from healthy, younger individuals to the infirm elderly since death is no longer a prerequisite to body donation. Additionally some of the uncomfortable issues surrounding the relationship of the body, soul, and afterlife that prevent body donation for research purposes are removed from the equation, thereby opening up a whole new world of potential donors.

3D modelling and visualisation in other fields, including computer sciences and forensic anthropology also impact healthcare. Forensic facial reconstruction is the practise of modelling approximating the face of an unidentified deceased person from the skull for the purpose of eliciting recognition. The practice has traditionally been carried out using clay; FaceIT, a recent method developed by Dr Davy-Jow at the University of Sheffield, enables 3D reconstructions to be carried out entirely in virtual space. The skull is obtained from either CT or laser surface scanning and muscles and facial features are modelled with the aid of a feature bank compiled from surface scans of living individuals. The 3D models can then be disseminated to the media or viewed on the web. Researchers in Computer Science are investigating methods by which an image of the skull surface could also be extracted from MRI data, allowing for craniofacial research on using living individuals without radiation exposure associated with CT. This will be a significant advance for medicine as well, providing an alternative to CT scanning in patients with contraindications such as pregnancy.

Anthropologists have also been using laser scanners to reconstruct full-body musculoskeletal models of ancient human ancestors from fossil data for the purpose of investigating locomotor and energetic behaviour. Such simulation and model combinations have potential applications in physical therapy or appendicular prosthetics, as the gait outcome of different devices could be modelled and tested before fitting to the patient.



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The Research Centre for Human Identification (RCHI) at the University of Sheffield Department of Archaeology is at the forefront of new research in forensic anthropology and forensic facial reconstruction. Members of RCHI, in partnership with the Animal Simulation Laboratory at the University of Manchester have been involved in virtual modelling of ancient hominins from fossil materials. This research has exciting applications both for facial prosthetics as well as modelling gait and movement outcomes in appendicular prosthetics. Enhanced dissection research is being carried out in conjunction with the Virtual Anatomy Lab at USF College of Medicine. Contact: Steph Davy-Jow at s.davy@sheffield.ac.uk.

The University of Sheffield's Academic Unit of Medical Physics is at the forefront of modelling and simulation in medicine, and is developing predictive tools that will be used to improve clinical diagnosis and interventional planning as well as contribute to the development of improved medical devices. The unit has an international reputation in cardiovascular research, including the development and application of tools for biomedical simulation. Contact: Pat Lawford at p.lawford@shef.ac.uk.

Medical Engineering at Sheffield Teaching Hospitals NHS Trust is contributing to VR surgical research and is developing the SKATS project.
Contact: Avril McCarthy at avril.mccarthy@sth.nhs.uk.

The Oral Biomaterials Research Group at the University of Sheffield's School of Clinical Dentistry is using 3D models to create dental and maxillo-facial prosthetics, implants, and novel sports mouth guards with concussion-preventing properties.
Contact: Professor Richard van Noort at r.vannoort@sheffield.ac.uk.

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