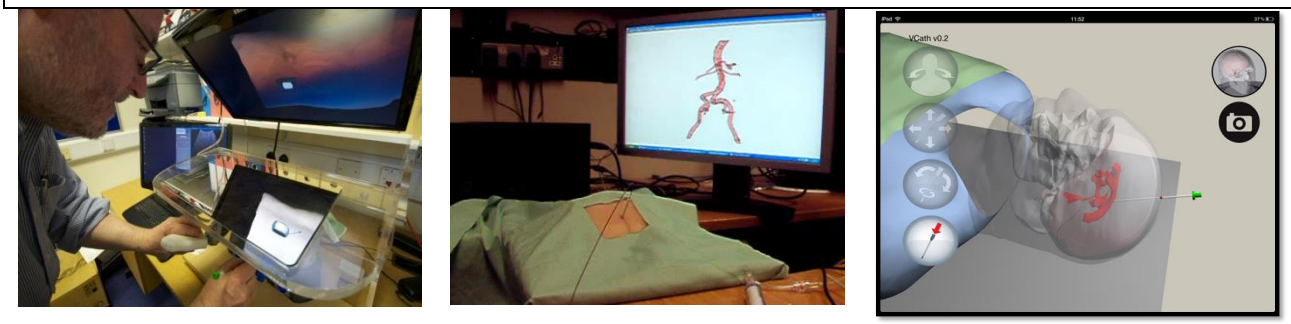
Institution: 10007857 – Bangor University
Unit of Assessment: UoA 11
Title of case study: Minimally invasive procedural training for clinicians using virtual patients

1. Summary of the impact (indicative maximum 100 words)

We demonstrate the impact of deploying real time 3D computer graphics and haptics technologies in the context of training minimally invasive procedures. It is widely accepted in medical specialties that a reform in teaching methods must be made to meet today's high volume training requirements. Receiving instruction in a core set of skills and procedures before novice practitioners are exposed to the traditional, patient based, apprenticeship model has been shown will reduce the time needed to acquire skills, maintain competence, and reduce the initial errors made on patients. The case study centres on three simulators developed at Bangor (Figure 1).



A. Ultrasound guided needle puncture *B. Interventional Radiology – Seldinger Technique* *C. Neurosurgery – Vcath iPad App*

Figure 1: Minimally Invasive Procedural Training Simulators

2. Underpinning research (indicative maximum 500 words)

Since 2003, Bangor School of Computer Science has led and coordinated multi-disciplinary research to build and deploy virtual patient systems for training minimally invasive procedures. The collaborations have involved computer scientists from Bangor, Imperial, Leeds and Hull; clinicians from Liverpool, Leeds and Cardiff, clinical engineers from Liverpool, and psychologists from Manchester. The research team from Bangor involved in this work are:

- Prof Nigel W. John, research management, implementation, coordination and commercialisation activities, 2003 – present
- Dr Franck Vidal, PhD Student (2003-8), Research Officer at Bangor, 2006-2008, appointed as a lecturer at Bangor, 2011
- Dr Chris Hughes, Research Officer, 2006 – 2013
- Dr Serban Pop, Research Officer, 2007 – present
- Dr Llyr ap Cenydd, Research Officer, 2007 – 2013, appointed as a lecturer at Bangor, 2013
- Prof Michael Rees, Consultant Cardiologist, School of Medical Sciences and Betsi Cadwaller University Health Board, 2005 - present
- Prof Derek Gould, Consultant Interventional Radiologist (Royal Liverpool Hospital) and Honorary Professor in Bangor School of Computer Science, 2006 – present
- Dr Tim Coles, PhD student, 2008-2011

A virtual patient is a sophisticated computer model of a human that can deliver accurate real time physiological responses to a trainee clinician using their natural senses and skills. Variations in patient anatomy and pathology, interaction between surgical tools and tissues, and human physiology such as respiration and blood flow must all be taken into account. The main impact of using virtual patients has been to reduce risk to real patients, reduce clinical training costs, and

help clinicians maintain skills.

The Bangor team developed algorithms for haptic effects of a needle penetration into tissue of the virtual patient, generating ultrasound-like images from CT source data, GPU implementations of X-Ray and fluoroscopy image generation, and managed the integration of the simulators. More specifically we:

- Proposed a volume haptic model for simulating needle puncture into different tissue types, using patient specific (CT) data [3.1].
- Designed and built a novel hardware haptic needle holder interface and simulation software (Fig 1B) [3.2]. EPSRC (EP/E002587), award to Bangor (John PI): £342,005 (total grant: £1,858,982). Patent pending [3.4]. This invention supports the introduction and orientation of a real needle into the virtual patient, assists with guiding the needle, and includes a pressure sensor to detect the position of the operator's finger tips.
- Developed a haptics simulation of a virtual ultrasound scanner that is used to guide the needle to the correct location inside the patient (Fig 1A) and utilises GPU-accelerated simulations of X-Ray transmission imaging [3.3]. Dept. of Health HTD Programme, award to Bangor (John PI): £108,051(total grant: £450,213).
- Produced the first prototype simulator to use augmented reality as a training aid in interventional radiology [3.5].
- Acquired data from actual procedures for use in and validation of simulations. For example, worked on optimisation of angioplasty by investigating the mechanism of balloon angioplasty and using intravascular imaging.
- Produced a novel tablet based training tool (VCath) for practicing a neurosurgery procedure on an iPad (Fig 1C).
- Have written well cited position papers on haptics in medical simulation [3.6] and intravascular imaging and measurement (Rees, 2011, 40 citations).

3. References to the research (indicative maximum of six references)

1. **F.P. Vidal, N.W. John**, A.E.Healey, **D.A. Gould**, "Simulation of Ultrasound Guided Needle Puncture using Patient Specific Data with 3D Textures and Volume Haptics", Computer Animation and Virtual Worlds. Vol 19, Issue 2, pp111-127, 2008, Online ISSN: 1546-427X, Print ISSN: 1546-4261. DOI: 10.1002/cav.217
   63 citations (Google Scholar November 2013). Returned in RAE 2008
2. V. Luboz, **C.J. Hughes, D.A. Gould, N.W. John,** F. Bello, "Real-time Seldinger Technique Simulation in Complex Vascular Models", International Journal of Computer Assisted Radiology and Surgery. Vol.4 No. 6, p 589-596. 2009. DOI: 10.1007/s11548-009-0376-0. *15 citations (Google Scholar November 2013) (submitted to REF2014 ID 1102).*
3. P.F. Villard, **F.P. Vidal**, C.Hunt, F. Bello, **N.W. John**, S. Johnson, **D.A. Gould**, "A Prototype Percutaneous Transhepatic Cholangiography Training Simulator with Real-time Breathing Motion", International Journal of Computer Assisted Radiology and Surgery. Vol.4 No. 6, p 571-578. 2009. DOI: 10.1007/s11548-009-0367-1
   17 citations (Google Scholar November 2013)
4. **C. J. Hughes, N.W. John**, "Haptic Needle as part of Medical Training Simulator", EP Patent 2,497,077, US Patent 20,120,219,937, 2011
5. **T.R. Coles**, **N.W. John, D.A. Gould** and D.G. Caldwell, "Integrating Haptics with Augmented Reality in a Femoral Palpation and Needle Insertion Training Simulation" IEEE Transactions on Haptics: Special Issue on Haptics in Medicine and Clinical Skill Acquisition, vol. 4., no. 3, pp 199-209, May-Jun 2011, DOI: 10.1109/TOH.2011.32
   15 citations (Google Scholar November 2013) (submitted to REF2014 ID 1101).
6. **T. R. Coles**, D. Meglan, **N. W. John**, "The Role of Haptics in Medical Training Simulators: A Survey of the State of the Art". IEEE Transactions on Haptics, vol. 4, no. 1, pp. 51-66, Jan.-Mar. 2011, DOI:10.1109/TOH.2010.19
   73 citations (Google Scholar November 2013) (submitted to REF2014 ID 1104).

(Authors in **bold** are from the Bangor team)

4. Details of the impact (indicative maximum 750 words)

As a result of the CRaIVE collaboration (5.6), two unique high fidelity training simulators for interventional radiology and cardiology procedures have been deployed, one of which was awarded a European Medical prize in 2009 for its "innovative use of computer graphics in a complex system that is already far advanced towards clinical use" (5.7). Related work is on-going to utilise mass market hardware such as tablet computers (5.10, 5.11). The Bangor team have taken the lead role in exploitation activities. Optimisation work carried out on interventional procedures such as angioplasty also provides unique data that can be exploited in the next steps of the training simulator after the catheter has been deployed. These activities contributed directly to a £1.2 million grant award in 2011 from the Wales Government that has established an Advanced Medical Imaging and Visualization unit (March 2011), led by John, with a remit to work in direct collaboration with the NHS delivering added value to everyday practice in hospitals through the use of visual computing technologies (5.3). The VCath App (5.11) and an electric wheelchair driving simulator (5.4) are two examples of simulation outputs from the unit at Bangor.

The simulators provide an objective assessment of task performance and the Bangor team contributed to novel metrics that provide, arguably, the first opportunities for validated proficiency assessments in interventional radiology needle access. The simulators have been rigorously validated by our psychology collaborators (5.8, 5.9) after full ethical approval was obtained. These content, face and construct validity, and skills transfer studies show that training on a virtual patient does provide a demonstrable improvement of users' performance. In training a simulated percutaneous nephrostomy (an image guided needle puncture), results from 53 participants showed that 78% of participants had indicated that the design was realistic, with content validity being rated averagely for all critical task steps; 83% of participants found the simulator a useful model for training skills for nephrostomy. In training the Seldinger Technique, results from the 28 participants who completed the simulated procedure, lend support for the simulator's face validity (82% agrees the simulator would be effective for learning basic skills and 86% believes it would be useful in learning how to use equipment). In addition, results from 26 radiology registrars who completed four trials on the simulator, showed that on average, participants' performance improved on all metrics over four trials on all metrics used to assess performance. The cost of hardware components used in the this work is modest, totalling under £10,000 for each high fidelity simulator, including haptics interfaces, offering an affordable solution to skills acquisition within a credentialing organisation's curriculum, as well as for simulation training centres and hospitals' training programmes.

We have also been collaborating with neurosurgeons to produce a low fidelity training application for deployment on the iPad computer tablet platform (5.1, 5.2, 5.11). The Bangor team have implemented a tool for learning the ventricular catheterisation procedure, which involves inserting a cannula into the ventricles within the brain so that fluid can be drained. The VCath App is the world's first example of an interactive procedure training tool to be made available on an iPad using a virtual patient and a finger gesture interface. The App passed Apple's quality assurance checks at the first attempt and is available for free download on the iTunes store. Over 6,500 downloads world-wide occurred since its launch in October 2012, and the current average is over 400 downloads per month, demonstrating far reaching dissemination. Further funding from NISCHR has been awarded for a validation study of VCath. Many other training tools for targeting tasks such as for nephrolithotomy (removal of kidney stones) can be similarly delivered and we are leading the way forward in this area.

License agreements with companies operating in the surgical simulation marketplace have been discussed, and are on-going, e.g., an evaluation agreement is in place with G-coder Systems AB of Sweden who market surgical training interfaces (5.5). However, more direct deployment in the short term has been based on a public domain model. Advanced Practice Courses using the interventional simulators are being planned since the start of 2013 with the indicated approval of the British Society of Interventional Radiologists and road shows have been organised in which the training simulators are made available free of charge with support from the Bangor team. The next

road show event will be held at Ysbyty Gwynedd in January 2014.

5. Sources to corroborate the impact (indicative maximum of 10 references)

Neurosurgeon collaborators:

1. **Liam Gray**, Institute of Psychological Medicine and Clinical Neurosciences, Cardiff University, GrayWP@cardiff.ac.uk;

2. **Nick Phillips**, Leeds General Infirmary, Nick.Phillips@leedsth.nhs.uk.

3. The Senior Project Manager at NISCHR can be contacted for corroboration on Bangor's leading role in the Advanced Medical Imaging and its impact on everyday practice in hospitals using visual computing technology.

4. Clinical contacts to have benefitted include: the Clinical Director of the North Wales Medical Physics, Ysbyty Glan Clwyd Hospital, who can be contacted for corroboration.

5. The CEO of G-coder Systems AB, Sweden (http://www.g-coder.com) can confirm interest of using simulator software from Bangor in commercial domain.

6. CRaIVE (Collaborators in Radiological Interventional Virtual Environments) Network http://www.craive.org.uk/

7. Eurographics Medical prize (2009). Awarded second place for: ImaGINe-S: Imaging Guided Interventional Needle Simulation (Fig 1A). http://www.eg.org/images/stories/awards/dirk_bartz_price/halloffame_20120525.pdf

8. SJ Johnson, CM Hunt, HM Woolnough, M Crawshaw, C Kilkenny, DA Gould, A England, A Sinha, PF Villard. Virtual reality, ultrasound-guided liver biopsy simulator: development and performance discrimination. British Journal of Radiology. 85.1013 (2012): 555-561, DOI: 10.1259/bjr/47436030.

9. SJ Johnson, SM Guediri, C Kilkenny, PJ Clough. Development and validation of a virtual reality simulator: human factors input to interventional radiology training. Hum Factors. (2011) Dec;53(6):612-25. http://www.ncbi.nlm.nih.gov/pubmed/22235524

10. "How a brain surgery app could save lives", BBC News coverage on the neurosurgery iPad App training tool (VCath, Fig. 1C), January 2013 (http://www.bbc.co.uk/news/uk-wales-20948542).

11. iTunes store download link: https://itunes.apple.com/sg/app/vcath/id568887198?mt=8