

Impact case study (REF3b)

Institution: King's College London
Unit of Assessment: UoA15 – General Engineering
Title of case study: Platform for Image-Guided Treatment of Arrhythmia
1. Summary of the impact
<p>Atrial fibrillation (AF), a form of cardiac rhythm disturbance, significantly increases risk of stroke, heart failure and sudden death. The Division of Imaging Sciences and Biomedical Engineering at King's College London and Philips Healthcare collaborated to develop a platform for guiding cardiovascular catheterisation procedures in patients with AF. The EP Navigator is a commercial, clinical product that integrates pre-acquired magnetic resonance and computer tomography images with real-time X-ray fluoroscopy. This enhances visualisation, thereby reducing procedure time and the patient's exposure to radiation. The EP Navigator is used in around 350 out of 2,000 centres worldwide that carry out ablation therapies for cardiac arrhythmias, despite strong competition.</p>
2. Underpinning research
<p>Atrial fibrillation (AF), a form of cardiac rhythm disturbance that greatly increased the risk of stroke, heart failure and sudden death, is a major healthcare problem that currently affects around half a million people in the UK. Incidence is expected to double by 2025 as a result of an increase in the aging population. Intervention for AF by ablation is usually performed under X-ray guidance; however, this imaging technique offers only two-dimensional information and very poor visualisation of the areas under investigation. This procedure requires great skill and often takes several hours, resulting in significant radiation exposure to patients and medical staff. The outcome of this procedure varies significantly and approximately 30% of the patients have to be treated more than once.</p> <p>Pre-procedural three-dimensional (3D) imaging techniques, such as computer tomography (CT) and magnetic resonance imaging (MRI), are very useful when planning ablation procedures. However, these techniques cannot be applied during the procedure. To overcome the time and difficulty factors involved in treating AF, the Division of Imaging Sciences and Biomedical Engineering at King's College London (KCL) has investigated advanced image-guidance techniques. The main investigators involved in this research are Rhode (2001-present, Research Fellow and subsequently Senior Lecturer), Schaeffter (2006-present, Professor), Hill (2000-2005, Senior Lecturer and subsequently Professor) and Razavi (2000-present, Lecturer and subsequently Professor).</p> <p>The concept of using pre-procedural 3D imaging to augment real-time intra-procedural imaging was first investigated by imaging researchers at KCL during the microscope-assisted guided interventions (MAGI) project that focused on guidance for neurosurgery [1]. In 2002, the novel approaches developed in the MAGI project were translated to cardiovascular applications when researchers at KCL developed technology that for the first time allowed the integration of pre-acquired MRI and real-time X-ray fluoroscopy images for guiding cardiovascular catheterisation procedures. Here, optical tracking was used to determine the transformation matrices relating MR and X-ray image coordinates. By calibrating the X-ray projection geometry and tracking the X-ray C-arm and table, the KCL researchers were able to align MRI-derived 3D cardiac models with live X-ray images. This allowed either a live 2D projection X-ray image of the catheters or a 3D reconstruction of the catheters made from multiple X-ray images, to be overlaid with an anatomical model derived from previously acquired MRI in an accurate and robust way [2].</p> <p>This off-line validation was followed by real-time implementation, validation and testing on patients requiring either radiofrequency ablation or aortic stent implantation. As a result, the technique was extended by providing an improved calibration stage, real-time guidance during cardiovascular catheterisation procedures and further off-line analysis for mapping cardiac electrical data to patient anatomy. During a procedure, the guidance system provided a real-time combined MR/X-ray image display consisting of live X-ray images with registered, recently acquired, MR-derived anatomy. Here it was shown that it was possible to reconstruct the location of catheters seen during X-ray imaging in the MR-derived patient anatomy [3].</p>

The above developments were limited to special hybrid X-ray and MR systems. Building on these, a system dedicated to arrhythmia treatment was developed to allow use of the overlay technology in standard cardiac catheter laboratories that are present in all major hospitals. Techniques were developed to allow automated registration of 3D models derived from CT or MR images [4]. These techniques used X-ray-based 3D reconstructions of catheters placed within the chambers of the heart and the great vessels to constrain the alignment of the 3D models to the fluoroscopy images. The motion of the heart during the respiratory cycle was compensated for to increase accuracy of the overlay [5,6]. Motion compensation approaches were developed using patient-specific models of the respiratory motion of the heart from MRI [5]. These allowed for complex affine motion. More simple translational models were also implemented using the 2D motion of structures that were automatically detected and tracked in the fluoroscopy images, such as the tracheal bifurcation, the diaphragm, the left heart border and the radio-opaque electrodes present on standard electrophysiology catheters. The 3D anatomical models of the heart were augmented with functional information, such as the presence of myocardial scarring from previous ablations [7] and the ability to map electrical information [8]. Algorithms were developed for the automated extraction and display of scarring from delayed contrast enhancement MRI using fast projection techniques [7]. Real-time electrical mapping was implemented by combining fast tracking of electrical measurement catheters and predictive signal interpolation methodology [8]. These developments led to a comprehensive integrated solution for the interventional treatment of cardiac arrhythmias. All developments were individually validated using a systematic approach going from in-silico phantoms to physical phantoms followed by testing using off-line clinical data and finally real-time clinical cases.

3. References to the research

1. Edwards PJ, King AP, Maurer CR Jr, de Cunha DA, Hawkes DJ, Hill DL, Gaston RP, Fenlon MR, Jusczyck A, Strong AJ, Chandler CL, Gleeson MJ. Design and evaluation of a system for microscope-assisted guided interventions (MAGI). *IEEE Trans Med Imaging* 2000;19(11):1082-93. Doi: 10.1109/42.896784
2. Rhode KS, Hill DL, Edwards PJ, Hipwell J, Rueckert D, Sanchez-Ortiz G, Hegde S, Rahunathan V, Razavi R. Registration and tracking to integrate X-ray and MR images in an XMR facility. *IEEE Trans Med Imaging* 2003;22(11):1369-378. Doi: 10.1109/TMI.2003.819275
3. Rhode KS, Sermesant M, Brogan D, Hegde S, Hipwell J, Lambiase P, Rosenthal E, Bucknall C, Qureshi SA, Gill JS, Razavi R, Hill DL. A system for real-time XMR guided cardiovascular intervention. *IEEE Trans Med Imaging* 2005;24(11):1428-440. Doi: 10.1109/TMI.2005.856731
4. Truong MV, Gordon T, Razavi R, Penney GP, Rhode KS. Analysis of catheter-based registration with vessel-radius weighting of 3D CT data to 2D X-ray for cardiac catheterisation procedures in a phantom study. *STACOM* 2011:139-148
5. King AP, Boubertakh R, Rhode KS, Ma YL, Chinchapatnam P, Gao G, Tangcharoen T, Ginks M, Cooklin M, Gill JS, Hawkes DJ, Razavi RS, Schaeffter T. A subject-specific technique for respiratory motion correction in image-guided cardiac catheterisation procedures. *Med Image Anal.* 2009 13(3):419-31. doi: 10.1016/j.media.2009.01.003
6. Ma Y, King AP, Gogin N, Gijsbers G, Rinaldi CA, Gill J, Razavi R, Rhode KS. Clinical evaluation of respiratory motion compensation for anatomical roadmap guided cardiac electrophysiology procedures. *IEE Trans Biomed Engineering* 2012;59(1):122-31. Doi: 10.1109/TBME.2011.2168393
7. Knowles BR, Caulfield D, Cooklin M, Rinaldi CA, Gill J, Bostock J, Razavi R, Schaeffter T, Rhode KS. 3-D visualization of acute RF ablation lesions using MRI for the simultaneous

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determination of the patterns of necrosis and edema. IEEE Trans Med Imaging 2010;57(6):1467-475. Doi: 10.1109/TBME.2009.2038791

8. Gao G, Chinchapatnam P, Wright M, Arujuna A, Ginks M, Rinaldi CA, Rhode KS. An MRI/CT-based cardiac electroanatomical mapping system with scattered data interpolation algorithm. ISBI 2010: 464-467

Grants:

- 2006-2009. PI: R Razavi, Engineering and Physical Sciences Research Council, Electro-anatomical fusion for guiding EP procedures and patient specific modelling, £800k
- 2006-2009. PI: R Razavi, Technology Strategy Board and Philips Healthcare: Electrophysiology Platform for Image-Guided Arrhythmia Management, £1M
- 2008-2012. PI: R Razavi, European Union Framework Programme 7: euHeart, £1.5M
- 2009-2012. PI: K Rhode, Philips Healthcare: Ultrasound Assisted Interventional Guidance, £193k
- 2009-2012. PI: K Rhode, Philips Healthcare: 3D Imaging for Ablation Guidance, £233k
- 2011-2014. PI: M O'Neill & K Rhode, St. Jude Medical: Integration of MRI-derived Functional Information into the Velocity Mapping System, £338k

4. Details of the impact

Research at the Division of Imaging Science & Biomedical Engineering, KCL has led to the development of a platform for guiding cardiovascular catheterisation procedures in patients with atrial fibrillation. In 2005, the Division initiated their collaboration with Philips Healthcare on a joint research and development program focused on image-guided arrhythmia management, to translate this technology into a clinical product that allows the integration of pre-acquired MR and CT images with real-time X-ray fluoroscopy funded jointly by the Technology Strategy Board (TSB) and Philips Healthcare. The end result – the EP Navigator – was brought to market in 2008 and directly resulted from initial work carried out at the Division [2,3]. The package comprises an automatic CT 3D segmentation package (EP planner) and the CT overlay software (EP Navigator) [9a, 9b].

The partnership between KCL and Philips has enabled Philips to incorporate KCL innovations into the field of electrophysiology, with a strong focus on translating technology into clinical practice. The collaboration has also complemented Philips' focused internal R&D programmes by enabling earlier-stage, more exploratory research. As a result of the collaboration, many features of image-guided interventions developed at KCL have been integrated into the EP Navigator product [9]:

- EP navigator Rel.3 (2010): Automatic registration of 3D CT/ATG.
 - Automatic alignment of 3-D models and X-ray images [4]
- EP navigator Rel.4 (2011): Automatic respiratory motion compensation
 - Compensation for the moving heart [5,6]
- EP navigator Rel.5 (2012): Automatic fluoroscopy catheter tracking, integrated activation and voltage mapping based on sparse sampling [6,8]
 - Display of electrical information
- EP navigator Rel.6 (2013): MR based 3D myocardial scar overlay for AF/VT ablation and CRT guidance [7]
 - Ability to see already damaged or ablated areas

The EP Navigator has led to a range of further products from Philips, including the Heart Navigator [9c]. KCL is currently working with Biotronik, EP Navigator's distributor in Europe, to establish a training centre at St. Thomas' Hospital, London.

This integration into a commercial product platform has allowed broader dissemination of KCL technology into the world-wide healthcare market, as well as enabling multi-centre trials to study

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the clinical outcome of improved treatment procedures. Two of the important impacts brought about by use of the EP Navigator are the reduction of radiation dose and procedure time [10a] which lead to less patient morbidity and lower healthcare costs. Recent studies have also demonstrated the clinical utility of EP Navigator [10b] with the clinical outcome for patients using EP Navigator being similar to that of other leading navigation systems [10c]. Accordingly, out of approximately 2,000 centres worldwide that carry out ablation therapies for cardiac arrhythmias, the EP Navigator is currently used in around 350 centres, despite strong competition from other products. The EP Navigator has also been replicated and commercialised by the other leading manufacturers of cardiac catheterisation laboratories, including Siemens Healthcare and GE Healthcare.

Discussion of the Philips EP Navigator has spread to the general public as it has been featured in two documentaries on British television: BBC TV's Horizon – How to Mend a Broken Heart [11a] and Channel 4's Brave New World With Stephen Hawking – Health [11b].

5. Sources to corroborate the impact

9. Philips EP Navigator:

- a) Website:
http://www.healthcare.philips.com/gb_en/products/interventional_xray/Product/electrophysiology/electrophysiology_portfolio/electrophysiology_navigator.wpd
- b) Letter from Philips Healthcare corroborating KCL involvement with EP Navigator on file and at: <http://www.kcl.ac.uk/medicine/research/divisions/imaging/ref.aspx>
- c) Philips HeartNavigator:
http://www.healthcare.philips.com/gb_en/products/interventional_xray/product/interventional_cardiac_surgery/interventional_tools/heartnavigator/

10. References discussing utility of EP Navigator

- a) Sra J, Narayan G, Krum D, Malloy A, Cooley R, Bhatia A, Dhala A, Blanck Z, Nangia V, Akhtar M. Computed tomography-fluoroscopy image integration-guided catheter ablation of atrial fibrillation. *J Cardiovasc Electrophysiol* 2007;18(4):409–14.
- b) Knecht S, Skali H, O'Neill MD, Wright M, Matsuo S, Chaudhry GM, Haffajee CI, Nault I, Gijssbers GH, Sacher F, Laurent F, Montaudon M, Corneloup O, Hocini M, Haïssaguerre M, Orlov MV, Jaïs P. Computed tomography-fluoroscopy overlay evaluation during catheter ablation of left atrial arrhythmia. *Europace* 2008;10(8):931-38.
- c) van der Voort PH, Stevenhagen J, Dekker LR, Bullens R, Meijer A. Three-dimensional computed tomography overlay for pulmonary vein antrum isolation: Follow-up and clinical outcomes. *Neth Heart J* 2012;20(7-8):302-6.

11. KCL and the EP Navigator in the media

- a) BBC TV: Horizon. How to Mend a Broken Heart. Aired 12.Mar.2011.
<http://www.bbc.co.uk/programmes/b00ysh81>
- b) Channel 4: Brave New World with Stephen Hawking – Health. Aired 24.Oct.2011.
<http://www.channel4.com/programmes/brave-new-world-with-stephen-hawking>