Surgical and Interventional Engineering Doctoral Training Programme

Available projects

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Industry funded projects

Integrating Haptic and Visual data for Low Latency transmission

Project reference: SIE_26

Start Date: October 2020

Industry sponsor: Huawei

First supervisor: Sebastien Ourselin

Second supervisor: Hongbin Liu

Project summary: The advancement in haptic sensing together with telecommunication technology such as 5G enables the possibility of ultra-low latency wireless communication of haptic information. Low latency haptic wireless communication would allow user to feel and efficiently interact with an environment remotely in real time, opening up new applications ranging from healthcare service to new consumer devices. The size of haptic data is generally small, however the technology bottleneck is how to integrate and synchronize the haptic data with visual information which has increasing large data size, associate with complex data compression processes. Furthermore, this problem is exacerbated by the requirement of low latency transmission of combined haptic and visual data for real-time operation.

Project description:

In this PhD research, we will investigate methods to address the above challenge. We will first investigate approaches of synchronizing the haptic data with the visual data. Research will be carried out on how to reliably and automatically identify the cues about when and where the device is in contact with the environment within image frames, and how to continuously identify with the corresponding haptic signal and thus synchronize the two modalities together. Furthermore, we will investigate robotic middleware design, to embed the software to hardware with guaranteed real-time performance to achieve time-critical, fail-safe integration and synchronization of haptic and visual information.

To facilitate low latency data transmission via wireless communication, this research will further investigate methods of reducing the size of image data. In conjunction with the haptic/visual data synchronization method, the student will implement the state-of-the-art image compression techniques and evaluate the performances of data transmission through tele-operation via a haptic console. A range of experiments with low to high speed of device-environment interactions, together with simulated latency in the network, will be carried out to evaluate the performance of haptic/visual communication and identify the optimal standards.

In many scenarios involving haptic interaction, the region of interested is often focused on a localised area where the tool-environment interaction occurs. To this end, we would like to investigate how to use haptic information to identify the regions on the image where device-environment interactions are occurring, and regions in the image with high frequency changes or low frequency changes. Different image compression technique can be applied based on these criteria to further reduce the data size for transmission while in the same time maintain a high quality displace to the user.

Cardiac CT Atrial Motion to Estimate Atrial Fibrosis Burden

Project reference: DTP_SIE_20

First supervisor: Steven Niederer

Second supervisor: Ronak Rajani

Industry sponsor: Siemens

Duration: 3.5 years

Mode of study: Full time

Eligibility: Only home UK or EU/EEA candidates fulfilling the 3-year UK residency requirement are eligible for the EPSRC DTP studentships. EU/EEA applicants are only eligible for a full studentship if they have lived, worked or studied in the UK for 3 years prior to the funding commencing.

Project summary: The project would consist of four parts.

1) Using retrospective cardiac CT data set recorded in heart failure patients we will create a manually annotated dataset that will provide a gold standard for tuning and optimising cardiac CT atrial motion tracking. We will then evaluate and optimise conventional[1,2,3] or machine learning[4-6] feature tracking algorithms.

2) We will obtain ethics to recruit and scan 20 patients as a proof of principal pilot study. Cardiac CT scans (as part of research) and electro-anatomical voltage mapping (as part of routine clinical care) will be performed in each patient. CT scans will be processed using feature tracking and area strains and principal strains will be calculated. Strains will be projected on to an atlas-based fibre field to provide estimates of atrial fibre strain. We will then compare different indexes of atrial strain (area strain, fibre strain and principal strain) against low voltage regions (that correspond with regions of fibrosis) recorded during the electro-anatomical mapping. This will provide a validation that fibre strains can be used as an index of atrial fibrosis.

3) Patients will receive an atrial ablation and the fibrosis burden estimated by the strain indexes will be compared with their outcome after 6 months. This will provide pilot data to support the use of atrial CT mechanics for predicting atrial ablation outcome.

4) CT images can be reconstructed at different timings (5,10 or 20%). We will evaluate how this affects motion analysis.

Project description:

Atrial fibrillation (AF) is the most common arrhythmia[7]. AF affects 5.2 million Americans[8], costs the US up to $26 billion per year[9], and increases the risk of cardiovascular disease[10], stroke[11], and death[12].

Guidelines recognize that AF is "*complex and difficult for clinicians to manage*"[13]. Patients can be treated pharmacologically[14,15], by catheter ablation to isolate or destroy aberrant atrial tissue[16], or by AV node ablation, coupled with pacemaker implantation, to isolate the atria[16]. Unfortunately,

pharmacological treatments have profound side effects[14, 17], AF may recur in ~50% of AF ablation cases[18], and pacemaker dependency has inherent risks[19]. No single treatment is best in all cases. Consequently, ***selecting the optimal treatment for each AF patient remains a daily clinical challenge*.**

Precision therapies require accurate characterization of each patient's specific disease phenotype[20]. Pathological atrial fibrosis is a major contributor to sustaining AF[21], has been repeatedly implicated in its pathogenesis[22], and is proposed as a biomarker to guide personalizing treatment[23]. Cardiac magnetic resonance (CMR) late gadolinium enhancement (LGE) currently provides the only non-invasive estimate of atrial fibrosis. However, ***widespread adoption of atrial LGE-CMR has been hindered by difficult and non-standardized image acquisition and analysis techniques and minimal validation*[24].**

To overcome these challenges, we propose to use mechanics-based measures to identify localized atrial fibrosis. Atrial fibrosis fosters chaotic electrophysiology[25, 26], attenuates local atrial mechanics[27,22], decreases contractility, and increases stiffness[28-30]. This proposal exploits the mechanistic link between atrial fibrosis and atrial mechanics to develop and validate a mechanics-based classifier of atrial fibrosis.

Fibrosis is both regulated by[31-36] and alters[21, 37] cardiac mechanics. Global atrial mechanics correlate with fibrosis burden[37-40] and local strain correlates strongly (cross correlation 0.85-0.9) with ablation scar[41] and moderately (r=0.66 and AUC=0.66) with fibrosis[27, 42]. **These preliminary studies demonstrate that left atrial mechanics can provide a measure of fibrosis burden. However**, conventional ventricular 2D CMR does not capture the complex atrial anatomy and motion; 2) the thin atrial wall is not easy to image 3) the features that could be used for motion tracking are small requiring high-resolution high contrast imaging.

Drastic reductions in radiation doses with next generation cardiac computer tomography imaging combined with multiple detectors now make motion measurements with cardiac CT a viable clinical tool offering exceptional image quality with isotropic resolution. We wish to build on our use of cardiac CT to measure motion in the ventricles [43] to measure atrial motion from cardiac CT and test if measures of local strain correspond to invasive measurements of atrial fibrosis, measured using electroanatomic mapping systems at the time of their procedure.

Computational Modelling research area

Image-based computational system for guiding ablation treatment of atrial arrhythmias

Project reference: DTP_SIE_03

Start Date: October 2020

First supervisor: Oleg Aslanidi

Second Supervisor: David Nordsletten

Project summary: Atrial fibrillation (AF) the most common sustained cardiac arrhythmia that affects about 33 million people worldwide. The disease is associated with substantial levels of morbidity and mortality, high risks of developing heart failure and stroke, and therefore extremely high rates of patient hospitalizations.

Project description:

The overall economic burden of AF amounts to about 1% of total healthcare costs in the UK. Even advanced therapies, such as catheter ablation (CA), are highly empirical and have poor long-term outcomes, with about half of AF patients returning for the repeated procedures, which further contributes to the healthcare burden. Moreover, invasive CA therapy often results in extensive damage of atrial tissue, effectively restoring atrial electrical function at the expense of impairing its mechanical function.

We have recently demonstrated that magnetic resonance imaging (MRI) and image-based 3D computational modelling can help (i) identify locations of electrical drivers sustaining AF in relation to image-derived atrial fibrosis and (ii) evaluate atrial mechanical properties due to the presence of fibrosis and AF drivers, and how these change after CA. The current project will advance this research from the stage of mechanistic understanding AF electro-mechanics to the creation of patient-specific approaches for minimally-invasive CA therapy.

Main objectives of the current project are to 1) create patient-specific probability maps for the locations of AF drivers – target maps for CA therapy, 2) simulate minimally-invasive CA procedures that terminate AF with minimal damage to atrial mechanical function, 3) validate the model predictions using patient electro-anatomical mapping and imaging data and known clinical outcomes, and 4) develop a CA guidance system that integrates patient MRI data with the predicted target maps and ablation lesion patterns to inform therapy.

We will use MRI data from 50 AF patients acquired at St Thomas'. An efficient workflow has been developed in our group to reconstruct 3D atrial geometry and fibrosis distribution from LGE MRI, and to create image-based 3D atrial models. The workflow will be applied to each of 50 cases, and the resulting models will be used to simulate multiple AF scenarios. The most likely special locations of AF drivers across scenarios will be recorded to create a patient-specific CA target map. The targets will be used to simulate optimal CA scenarios for each patient, which aims to minimise the procedure time and the damage to atrial mechanical function. The latter will be facilitated by 3D atrial mechanics simulations using our CHeart platform. The simulated electrical activations and mechanical strains will be validated against electro-anatomical mapping and Cine MRI data from the

same patients. The predicted CA patterns will be validated by cross-correlation with the actual CA patterns applied to treat these patients and outcomes of a 1-year monitoring of the AF recurrence.

The image-based computational workflow will be integrated with commercial systems for therapy guidance developed by our two industry partners, Galgo Medical and Abbott. Galgo's ADAS software, which will be used as a framework, is fully compatible with Abbott's EnSite Precision™ system used for cardiac intervention guidance in the clinics worldwide. Hence, novel technology developed in this project will be integrated with this advanced system, enabling its delivery at the point of care for the benefit of clinicians and patients.

Predicating ablation volume for laser interstitial thermal therapy (LiTT) for computer-assisted planning of minimally invasive neurosurgery

Project reference: DTP_SIE_06

Start Date: October 2020

First supervisor: Rachel Sparks

Second Supervisor: Sebastien Ourselin

Project summary: Laser interstitial thermal therapy (LiTT) LiTT is a novel therapy which may provide a minimally invasive means of ablating structures within the brain. Thermal ablation is a lesioning technique that has been used in neurosurgery for many years with variable success. The main limitation to earlier methods were the unpredictable nature of thermal lesioning and the lack of real-time monitoring. LiTT is a laser catheter techniques that allows for real-time monitoring of lesioning under MR thermography. However, a critical part to the process, both in terms of safety and efficacy, involves pre-operative planning of the laser trajectory as this ultimate dictates ablation location and volume.

Project description:

Current computer-assisted planning techniques assume crude geometric approximation of the ablation volume, typically as a 15mm diameter around the laser catheter. However, brain vascularity, proximity to bone and the ventricles result in asymmetric tissue heating. Developing computational models to more accurately estimate the heat transfer, and ultimately predict ablation volume would enable more accurate placement of laser catheter, could provide guidance on the heating parameters to use to obtain optimal ablation results. We propose to develop computation modelling techniques to predict ablation volume and use these models to identify optimal laser catheter parameters.

The student will develop tools to predict ablation volume for selective lesioning of the amygdalohippocampal complex using a multi-center retrospective dataset of over 100 LiTT procedures. These procedures have a clearly defined trajectory approach, limiting the variability of the ablative volume between patients. For a limited set of patients (20) we have corresponding MR thermography data over the course of the procedure with which to learn and validate the course of heating.

Second, computational modelling and prediction of heating will be integrated into a computer-assisted planning software for the trajectory, and expected heating can be used to aid surgeons in planning trajectories. A prospective trial taking place at Dartmouth will be used to validate the accuracy of the predicted ablation volume.

Finally, if AHC ablation prediction is accurate, we will investigate expanding this method to other ablative procedures including corpus callosotomy and hypothalamic hamartoma where the approach and anatomy are more variable and may require more complex models of heat dissipation and its relationship to anatomy.

Improving the diagnosis and treatment of peripheral artery disease using computational modelling

Project reference: DTP_SIE_07

Start Date: October 2020

First supervisor: Jordi Alastruey

Second supervisor: Ronak Rajani

Project summary: This project will develop a multi-scale cardiovascular modelling framework tailored to the specificities of PAD that will allow us to provide efficient and accurate diagnostic tools, as well as valuable patient-specific, help-to-decision data for the treatment of PAD. The framework will be based on an approach that has previously been used for CAD.1,2

Project description:

The project objectives are:
Obj. 1: Development of a computational modelling framework for the study of PAD;
Obj. 2: In vitro validation of the computational framework;
Obj. 3: Clinical feasibility study.

The following tasks will be carried out to fulfil these objectives:

Task 1: Computational model development (18 months) – The framework will simulate detailed blood flow patterns in locally complex arterial geometries with stenosis, as well as global flow patterns in the systemic circulation. It will be based on our in-house tools created to assess blood flow in the aorta of hypertensive patients,3,4 and will include the following geometric scales: (i) detailed macro-vascular stenosis scale accounting for anatomically-correct arterial geometries reconstructed from computed tomography angiography (CTA) data; (ii) averaged macro-vascular scale describing pulse wave propagation in the larger systemic arteries; and (iii) micro-vascular scale in the capillary network which is responsible for the collateral perfusion observed in PAD patients and which could play an important role in guiding treatment. The model will be used to develop novel haemodynamic biomarkers for accurate PAD diagnosis and assess the optimal treatment procedure (e.g. pharmacotherapy, stenting, revascularisation).

Task 2: In vitro validation (9 months) – Our EPSRC-funded, state-of-the-art, 1:1 scale cardiovascular simulator rig (CVSR) of the heart and larger systemic arteries includes peripheral arteries of the lower limbs.5 Different types and degrees of lower-limb atherosclerotic lesions (e.g. single, sequential, diffuse) will be (i) designed based on real lesions' geometry, (ii) manufactured using 3D printing, and (iii) inserted into the lower-limb arteries of the CVSR. This will be used to validate the simulated blood pressure and flow data, especially in scenarios with complex sequential and diffuse lesions.

Task 3: In vivo validation (9 months) – The novel biomarkers developed in Task 1 and the ability of the computational framework to predict optimal treatment procedures will be tested in existing

patient cohorts (with a variety of PAD symptoms) from Dr Rajani's clinic, for which haemodynamic measurements and CTA imaging data are available pre- and post-operatively.

The project will improve PAD diagnosis and treatment by providing clinicians with a novel tool that combines haemodynamic measurements and medical images using validated, state-of-the-art, patient-specific models of blood flow. The integration of such tools in clinical routine is anticipated to improve PAD patient morbidity and mortality.

References

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3 Alastruey J, et al. On the impact of modelling assumptions in multi-scale, subject-specific models of aortic haemodynamics. J Royal Soc Interface 13(119):1–17, 2016
4 Vennin S, et al. Identifying hemodynamic determinants of pulse pressure – A combined numerical and physiological approach. Hypertension 70(6):1176–82, 2017
5 Gaddum N, et al. Relative contributions from the ventricle and arterial tree to arterial pressure and its amplification: an experimental study. Am J Physiol – Heart Circul Physiol 313(3):H558–67, 2017

Intra-operative planning software for congenital cardiac surgery

Project reference: DTP_SIE_11

Start Date: October 2020

First supervisor: Pablo Lamata

Second supervisor: Simone Speggiorin**,** GSTT

Project summary: One in 100 children are born with heart defects, of which a quarter will require surgery. Congenital heart diseases present as a spectrum of anatomical malformation, each consisting of infinite combinations of defects unique to the patient, and this presents an immense challenge to cardiac surgeons.

Project description: In dealing with newborns (or neonates), these highly specialized surgeons must operate on atretic great vessels (abnormal vessels circulating blood in and out of the heart) that are only millimeters thick – smaller than the equipment itself. In great vessel reconstructions, such as the Norwood procedure, donor tissue (or homograft) patches are used to repair the shape of the vessels to improve blood flow. Patch dimensions must be optimized to account for an almost infinite array of patient anatomies. Misshapen patches can have dire consequences for patients: cut too small they can result in obstruction; cut too large they can result in aneurysm. This places a heavy burden on surgeons with profound effects on morbidity and mortality.

The project's objective is to improve the surgical outcomes in congenital surgical procedures by an optimization and automation of the decision making process related to the personalization of surgical technique. Rather than catering for specific diseases, the scope of the project will be to produce a toolkit of planning models catered to individual anatomical defects. These include: atrial septal defects, ventricular septal defects, valve atresia and great vessel patch reconstruction.

The candidate will be expected to (1) develop methods to segment the relevant anatomy with minimal user input; (2) build a library of cases from retrospective data, recreating the decisions taken by surgeons; (3) develop algorithms to propose optimal anatomic and functional surgical reconstructions of the congenital defects; (4) develop and test strategies for an optimal intra-operative visualization of the outcome, exploring two main alternatives: 3D printing or augmented reality.

The general requirements for such solutions will be: (1) to support decision making processes, both pre- and intra- operatively, so that the surgeon can make better technical decisions in the heat of the moment; (2) to operate at millimeter accuracy to cater for unforgivingly small margins for error. The project is framed in the exciting phase of transferring ideas from the academic environment to a young and dynamic spin-out. The student will thus be supervised by an academic from the CMIB team at KCL, a pediatric surgeon from Evelina Hospital, and the entrepreneur that has launched Congenita Ltd. This PhD project will be one of the keystones in fulfilling the mission of improving survival rates for children undergoing corrective congenital surgery. Envisioned workflows will require close multidisciplinary collaboration with Congenita's technical lead, clinician champions, and business development team. The post will thus be an opportunity to build the R&D foundations for an early stage MedTech company. If the candidate demonstrates a good fit, we hope they will stay on as a product lead, with potential for equity ownership in the company.

Virtual pace mapping for optimised planning of catheter ablation procedures

Project reference: DTP_SIE_16

Start Date: October 2020

First supervisor: Martin Bishop

Second supervisor: Steven Niederer

Project summary: Pace mapping is a commonly used technique during catheter ablation therapy of ventricular tachycardia, that involves matching a paced-beat in the cath-lab to the ECG (QRS) morphology of the induced arrhythmia that is being targeted. However, it is a lengthy, and often inaccurate, procedure which also requires prior arrhythmia induction, increasing the risk to the patient. Our main aim is to develop a patient-specific computational modelling pipeline that allows accurate, and safe, identification of ablation targets via simulated pace-mapping. This will be enabled by combining detailed image-based anatomical models with methods to personalise activation sequences (QRS) using standard ECG and multi-electrode vest recordings following simple pacing. As ECG recordings of the clinical arrhythmia are problematic, we will also investigate the potential to perform simulated pace-mapping based on sensed arrhythmia data from the patients implanted devices (which the majority of ablation candidates have in-situ).

Project description:

Personalisation of anatomically-detailed patient-specific models
LGE MR imaging data will be used to construct anatomically-detailed computational ventricular and whole-torso models using existing pipelines. In this initial proof-of-concept, patients without implanted devices will be used; specifically, patients with ischemic heart disease and large, arrhythmic scars. We will also work closely with MR Physicists in the Dept (Seb Roujol) to develop sequences that enable LGE MR of patients with implanted devices for later incorporation into the modelling pipeline. Pacing data from the implanted device (paced at known site in the RV apex) will be used along with simultaneously recorded ECG. Simulated activation sequences and simulated ECGs will be used along with recorded patient pacing data to parameterise tissue conductivities of the ventricular models in a patient-specific manner. As only activation (QRS of ECG) is used in pace mapping, T-wave and action potential duration personalisation is not required, which represents a key advantage of our approach for accurate personalisation.

Simulated Arrhythmia Episodes
Sustained episodes of ventricular tachycardia (VT) will be simulated in the ventricular models. Multiple episodes will be simulated in each patient model by applying induction protocols from different sites. During these episodes, torso ECGs will be simulated using full bidomain simulations. This will allow detailed ECG recordings of the clinical VT. A trained clinician will assess the simulated VT episodes and identify the optimal ‘exit’ sites for catheter ablation targets, which will be used later for comparison.

Simulated Pace Mapping
Sites surrounding the scarred regions will be chosen and repetitive pacing performed at the cycle length of the recorded clinical VT (as done in the clinic). Sites will be chosen, not only on the endocardium (as in procedures), but also transmurally and epicardially, representing a distinct advantage of this in-silico approach. It is expected that many 1000s of points may be chosen (limited

only by CPU time) to enable accurate identification of targets. Simulations of pacing will be combined with novel reaction eikonal simulation methods, along with the lead-field approach to enable rapid simulations of ECGs in whole-torso models. At each site, simulated ECGs will be correlated with those recorded during the simulated clinical VT; as performed clinically, those sites having the highest correlation will be identified as ablation targets. The in-silico identified ablation targets will be compared with those identified by the clinicians previously.

Adaptation to Use Implanted Device Recordings

Current pace-mapping methods use only ECG recordings of the clinical VT. This is a major disadvantage, as this is often not available and difficult to obtain. The above pipeline will be repeated, but instead of simulating ECG recordings during the VTs, electrogram (EGM) recordings will be simulated from the exact location of the (multiple) sensing electrodes in the implanted devices. As less information-rich than ECG data, different and multiple recording/sensing vectors will be investigated from multipolar devices to obtain the optimal sensing settings to be used in future developments.

Validation

The constructed computational pipeline will be used with the novel MR sequences to obtain real clinical patient data in order to validate this method.

Investigating thrombosis formation in replacement aortic valves

Project reference: DTP_SIE_17

Start Date: October 2020

First supervisor: Jack Lee

Second supervisor: Tiffany Patterson, Guys' and St Thomas' NHS Foundation Trust

Project summary: Aortic stenosis affects 2% of the population over 65 years of age, that rises to >10% in over-75s, and carries a poor 50% mortality rate at two years.

Project description: The introduction of Transcatheter Aortic Valve Implantation (TAVI) in the past decade has provided a revolutionary alternative to Surgical Aortic Valve Replacement (SAVR) and has seen a rapid growth in the number of procedures. Following advancements in device design and procedural optimisation, the clinical outcomes of TAVI has acquired an excellent outlook, with risk of stroke and mortality rates reaching that of the normal population 3 months after the procedure. However, recent reports indicate that in around 15% of the TAVI recipients, leaflet thrombosis and reduced mobility is found, as reliably detected by HALT (Hypo-Attenuation and Leaflet Thickening) in CT imaging. Valve thrombosis increases risk of major cardiovascular events, and even if sub-clinical in the short term, can adversely affect the long-term durability of the implanted valves which would limit the expansion trans-catheter therapies to younger, lower surgical risk population. To this end, FDA have released a statement calling attention to this problem. Though oral anti-coagulation therapies are an option, currently there is no way to gauge the risk of valve thrombosis in patients, potentially raising the risk of bleeding and adverse outcomes.

Hypothesis: High transvalvular gradient at post-TAVI procedure is correlated with the development of valve thrombosis, modulated by a multifactorial interplay between the patient anatomy, bioprosthetic valve geometry, and haemodynamics.

Aims:

1. to predict patients at risk of leaflet thrombosis from standard clinical imaging data
2. to identify optimal valve configuration to minimise thrombosis formation

Work Plan:

This project will be conducted alongside a clinical investigation in which markers of leaflet thrombosis will be temporally recorded in patients of differing transvalvular hemodynamics. Haemodynamic modelling will enable a deeper quantitative analysis of data and predictive simulations. The clinical proposal is currently in review with the BHF.

1. The clinical data will be augmented through building ensembles of haemodynamic simulations, by permuting from available patient anatomies and known valve geometries (annulus diameter 23-29mm), deployed in various orientations. The routine clinical data includes pre-TAVI contrast enhanced CT and post-TAVI echocardiograms (n>50) from which the anatomy and boundary conditions can be estimated. Segmentation and meshing pipeline will be set up based on our previous work in biventricular image analysis, and CFD

simulations will be performed with our in-house code. Wall shear stress, turbulence and kinetic energy indices will be determined from the output of simulations.

2. A comprehensive collection of features will be quantified from the full modelling pipeline, including anatomical (annular size, annular geometry, calcification, distance between aortic annulus and coronary ostia, dimensions of sinus of Valsalva, LVOT size and orientation) and derived haemodynamic parameters. These parameters will be correlated with the degree of HALT observed in longitudinal CT scans performed in TAVI recipients. Spatial localisation of HALT on leaflets with respect to the features will also be investigated.

Computer-Assisted Interventions research area

Computational extraction of semantic information from hyperspectral imaging for surgical guidance

Project reference: DTP_SIE_02

Start Date: October 2020

First supervisor: Tom Vercauteren

Second supervisor: Christos Bergeles

Project summary: Optimal outcomes in neuro-oncology surgery are hindered by the difficulty of differentiating between tumour and surrounding tissues during surgery. In this project, we will advance intraoperative computational hyperspectral imaging (HSI) to achieve real-time tissue characterisation and thus enhance the neurosurgeon's visualisation. HSI provides rich high-dimensional intraoperative information but this cannot be directly visualised by the surgeon. This mandates the development of novel machine learning approaches for real-time semantic processing of HSI. We will consider interpretability by the surgeon of the computed information as a design constraint to deliver trustworthy learning-based semantic information extraction with algorithms that shine light on their decision process and inform the user when the data cannot be processed in a reliable manner.

Project description: Clinical studies have demonstrated that patients who undergo surgery and have their CNS tumour radically removed have a significantly longer survival than those who are left with residual tumour tissue after surgery. Surgery is often the primary treatment and the aim of neuro-oncology surgery is to remove as much abnormal tissue as safely possible. Successful neurosurgery to remove brain tumours depends on achieving maximal safe tumour removal: avoiding damaging sensitive areas that undertake vital functions and preserving crucial nerves and blood vessels. However, even with the most advanced current techniques, it may still not be possible to reliably identify critical structures during surgery. The identification of tumour and surrounding tissue is currently still based on surgeons' subjective visual assessment.

During surgery, neuronavigation solutions can map preoperative information to the anatomy of the patient on the surgical table. However, navigation does not account for intraoperative changes. Interventional imaging and sensing, such as surgical microscopy, fluorescence imaging, point-based Raman spectroscopy, ultrasound and intra-operative MRI, may be used by the neurosurgeon, but partly due to stringent operative constraints, tissue differentiation remains challenging. Advanced optical imaging techniques provide a promising solution for intraoperative wide-field tissue characterisation, with the advantages of being non-contact, non-ionising and non-invasive.

Hyperspectral imaging (HSI) is a camera-based optical imaging technique that exploits the ability to split light into multiple narrow spectral bands far beyond the conventional red/green/blue channels. It enables the acquisition of much richer information than what can be seen with the naked eye. While bearing rich high-dimensional information, the raw 2D+wavelength+time data that HSI produces is difficult to interpret for clinicians as it generates a temporal flow of three-dimensional information which cannot be simply displayed in an intuitive fashion on standard monitors (including

“3D”/stereo displays). Combined with a general increase in the use of imaging, with real-time HSI, the clinical team will face a data deluge that needs to be addressed.

We will develop real-time machine learning approaches to extract surgically relevant information from the massive high-dimensional HSI data stream and reduce the cognitive workload for the surgeon. Interpretability of the inference results will be put as a design constraint with methodologies rooted in Bayesian learning. Although snapshot HSI sensors allow to capture HSI data in real-time, their resolution is limited in terms of spectral and spatial domain, especially in comparison to modern endoscopic camera heads. Data is acquired with spatially interleaved and subsampled spectral bands. As an initial goal of the project, we will design a bespoke data-driven reconstruction algorithm to recover a fully sampled spatial and spectral response from the snapshot HSI. We will then develop algorithms for semantic interpretation of HSI video streams and pave the way for clinical translation of these solutions.

Device safety and visualisation in MRI-guided cardiac catheterisation

Project reference: DTP_SIE_05

Start Date: October 2020

First supervisor: Shaihan Malik

Second supervisor: Jo Hajnal

Project summary: MRI guidance for cardiac interventions usually requires the use of exclusively non-metallic instruments (guidewires and catheters, henceforth referred to as 'wires' for simplicity) in order to avoid radiofrequency heating. Such devices are being developed commercially and they can offer suitable performance for some procedures, however they often lack the mechanical stability and stiffness that is available from standard metal wires used in x-ray fluoroscopy. In addition, although MRI offers excellent visualisation of soft tissues, it is often a challenge to visualise these (usually plastic or fibreglass) devices using MRI.

Project description: A radically different approach being pioneered within BMEIS is to use an alternative RF transmission system within the MRI scanner. Instead of using the built-in "body coil" which can create large-scale currents on inserted wires, an on-body surface transmit array is used to generate the RF fields. This array contains multiple transmitters which can each produce their own RF field; the approach is known as parallel transmission (pTx). By measuring induced currents on inserted wires in real time it is possible to control the array to cancel out induced currents and hence produce safe MRI conditions for imaging. It is also possible to excite the wires preferentially (using very low power) in order to visualise them clearly, providing a promising route for intraprocedural device visualisation.

Currently we have a prototype system built for performing these procedures at 1.5T and have shown that in principle such procedures are safe. However a workable clinical capability requires solving key challenges outlined below; this project aims to address these areas and will link in with further grant funding to produce first in man testing.

Objective 1: high frame rate real-time wire visualisation using AI

Wire excitation using pTx to directly couple to wires has been shown to be a viable method for visualisation, however current frame-rates (approximately 0.5fps) are much lower than required (5-10fps). The student will investigate use of fast MR methods, coupled with real-time image reconstruction and whole-wire segmentation to generate overlays for anatomical images. Wire-only images are highly spatially sparse and so can be accelerated using sparsity based image reconstruction methods. Direct reconstruction of a wire-segmentation for image overlay using AI augmented reconstruction may provide the low latency necessary for real-time visualisation and could be used to infer visualisation of the wire tip which is often hard to see using the proposed MRI method alone.

Objective 2: Current sensing

'Active decoupling' of induced currents requires continuous monitoring; for cardiac interventions one way to do this is to include physical sensors at the wire insertion point. Other possibilities include monitoring of the coil scattering parameters, or direct MRI based measurements using very

fast low power imaging. The student will investigate miniaturised sensors with support from Dr. Bergeles, as well as rapid MRI measurements that can be interleaved within standard imaging sequences.

Objective 3: Clinical workflow

Demonstrations of the technology have so far been limited to simple experimental scenarios, but have not explored operation under clinical conditions. The student will work with Dr Pushparajah (clinical co-supervisor) to perform realistic imaging tests using purpose built (existing) phantoms, to identify and resolve bottlenecks.

Computer-assisted planning for cervical needle injection

Project reference: DTP_SIE_09

Start Date: October 2020

First supervisor: Marc Modat

Second supervisor: Rachel Sparks

Project summary: Needle-based spine drug delivery is a procedure that is commonly used to reduce patients' pain. This is achieved by injecting either local anaesthetic or steroid at the site of pain in order to directly reduce the pain or to decrease inflammation and swelling. The preferred target is defined from the patients' symptoms. Common targets include the surrounding space of the spinal cord (epidural), the bones' joins (facet), the nerve root or the intervertebral disks (discography). All these procedures require precise identification of the source of pain and careful planning of the needle trajectory. Both the identification of the target site and the planning are currently performed by experienced surgeons or radiologists, without any planning tool apart from a volumetric CT at the beginning of the procedure and multiple contrast enhanced CTs during the injection.

Project description: One of the key planning challenges during injections is that the patients' pain usually occurs from abnormal stress between joints or broken bones. Such patients' often have abnormal anatomy or implants which may require the surgeon to deviate from standard trajectory approaches. For this project, we propose to develop a planning tool to support clinicians undertaking these procedures. This will be achieved by focusing on three main tasks.

First, the student will create a tool to automatically localise the target area. Using natural language processing, clinical reports that contains the symptoms will be processed to determine the vertebrae level as well as the side(s) that needs treatment. From this information, reinforcement learning strategies will be used to label the target on CT in the presence pathology. Reinforcement learning has been shown to be an effective tool to identify spine anatomy such as vertebrae, disk and canal. This task is otherwise challenging due to the similarities from one area to another. In 70% of the available retrospective cases, MRI of the neck area are also available. This will be used to augment the CT images in order to better identify the nerves and other non-bony tissues.

Second, using statistical tools, the retrospective data will be analysed to define, in 3D rather than 2D, the needle trajectory properties that differentiate good patient outcomes from bad patient outcomes. Example properties could potentially include minimal distance to the bone, distance to structure at risk, needle length or needle bending amongst others. These markers will then be used to implement an automated planning tool. The planning tool will leverage on the software infrastructure of ongoing projects for keyhole tool placement, especially EpiNav.

Last, the student will assess the feasibility to develop a learning-based prognosis tool inferring from needle trajectory. This would potentially enable to later optimise the needle placement so that it maximises the benefit to the patient.

Single-sequence multi-dimensional MRI for customised intervention planning of brachytherapy in cervical cancer

Project reference: SIE_23

Start Date: October 2020

First supervisor: Isabel Dregely

Second supervisor: Sebastien Roujol

Project summary: Brachytherapy is an important part of treatment for patients with cervical cancer. Advanced MRI-based image guidance has potential to transform clinical practice in the direction of *customised* brachytherapy enabling better accuracy of target and organs-at-risk delineation as well as individualised dose administration for improved clinical outcome regarding local control and overall survival.

Primary Aim: To develop a novel multi-dimensional MRI sequence (3D spatial + quantitative T2 and diffusion information) for precision brachytherapy treatment guidance

Secondary Aims: 1) To assess the geometric accuracy of the sequence including depiction of the applicator in phantoms and patients; 2) To assess the accuracy and reproducibility of quantitative biomarkers (T2/ADC) in phantom, healthy volunteers and patients.

Project description: Around 3,200 women are diagnosed with cervical cancer in the UK each year[1]. High Radiation Dose Brachytherapy (HDR-BT) involves the use of a locally placed radioactive source and is an important component in the treatment. MR imaging is used for detection and staging of cervical cancer and now also increasingly used for planning of brachytherapy treatment [2,3] . Compared to standard CT-based planning, MR has clear advantages due to superior soft tissue contrast providing opportunities for 1) superior identification of target volume while simultaneously minimising toxicity to adjacent organs; 2) customisation of dose delivery by providing multi-dimensional information (biomarker changes vs time) during the entire course of HDR-BT; and 3) checking the accurate placement of the applicator before radiation dosing. However, clinical challenges are that current MR sequences are limited to 2D thick slices, are prone to geometric distortions and image artifacts can induce errors when estimating the exact applicator position. Importantly, 'functional' MR sequences, despite their great promise for 'biology-based' radiation dose customisation, are currently not feasible as image quality is not sufficient for intervention.

[1] www.cancerresearchuk.org
[2] Tanderup et al. Semin. Radiat. Oncol. 2014;24:181–191.
[3] Sullivan et al. Radiographics 2018;38:932–944.

Hypothesis:

A novel multi-dimensional MRI sequence to acquire both anatomical and functional data with geometric precision in a single scan will reduce treatment margins, improve applicator placement

and enable customisation of dose delivery to improve image-guided brachytherapy compared to our current standard imaging practice.

Project plan:

WP1: Develop a novel multi-dimensional MRI sequence optimised for precision radiotherapy

A novel single-scan 3D MRI sequence, using interleaved magnetization preparation to encode both T2 and diffusion-weighted image contrast will be developed to specifically address the challenges for brachytherapy planning: To achieve 1) 3D isotropic high-resolution, 2) excellent geometric fidelity and 3) accurate depiction of applicator position. 1)-3) will be assessed using a 3D MRI geometric phantom, healthy volunteer and pilot patient data.

WP2: Quantification of anatomical and 'functional' biomarkers for customised intervention planning; Assessment of accuracy & reproducibility

Extension of the above MR sequence to obtain quantitative co-registered anatomical and functional biomarkers to facilitate customization of dose delivery. Accuracy and reproducibility of quantitative T2 relaxation time and diffusion apparent diffusion co-efficient measurements will be assessed in a MRI phantom study, healthy volunteers (n=10) and patients with cervical cancer (n=10).

WP3: Towards a clinical advanced MR-guided brachytherapy treatment pathway

Pilot data will be used to develop a pilot study with the aim of implementing an MRI based pipeline in the brachytherapy pathway.

Project timelines:

0-24 months (WP1&2): MRI sequence developed; phantom testing and healthy volunteer study commenced; data analysis commenced.

Deliverables:

- Novel single-scan MRI sequence incorporating 3D spatial, T2 & diffusion information as a WIP (Work-In-Progress package towards product in collaboration with industry partner Siemens) including image analysis package and manual;
- Publications submitted summarising technical evaluation.

24-36 months (WP3): Patient study commenced; Data analysis; Write up of publications.

Deliverables:

- Implementation of MR workflows in clinical pilot study in collaboration with radiology and radiotherapy clinical consultants;
- Publication submitted summarising pilot patient study.

36-42 months: Pilot studies completed; Finalise data analysis; Thesis write up.

Safe and accurate imaging with intracranial implants using a parallel transmit RF coil array

Project reference: SIE_25

Start Date: October 2020

First supervisor: Ozlem Ipek

Second supervisor: David Carmichael

Project summary: Intracranial electroencephalography (EEG) is used in the surgical assessment of patients with severe, drug resistant epilepsy to help identify the seizure onset zone. Intracranial depth electrodes are used to record the electrical activity of the brain, targeting areas thought to produce seizures. Anatomical targeting of the depth electrodes needs to be verified by post-operative imaging of the implanted depth electrodes by MRI. However, the radiofrequency (RF) fields used for MRI can electrically couple to the metallic implanted electrode and lead to an excessive RF current on the electrode producing a risk of local heating and tissue damage. Therefore, current MRI safety guidelines severely constraint the MRI protocol parameters for patients with implanted depth electrodes. This research project aims to design and build a new parallel transmit radiofrequency coil array that could significantly reduce the risk of implant heating while increasing the accuracy of imaging the human brain for epilepsy patients with implanted electrodes.

Project description: Intracranial electroencephalography (EEG) is used in the surgical assessment of patients with severe, drug resistant epilepsy to help identify the seizure onset zone. Electrodes are typically composed of 30-40cm wires with multiple electrode contacts that record signals within the brain. Typically, multiple electrodes are implanted in a wide range of configurations that are tailored to each patient. MRI post-implantation can be a useful way of verifying anatomical targeting of the electrode without potential confounding effects of brain spatial shifts that can occur during surgery (and limit the accuracy of localization of electrodes based on pre-implantation MRI and post-implantation CT). Further, the ability to study patients using MRI with intracranial electrodes offers the opportunity to better understand epileptic activity and potential therapeutics such as electrical stimulation [1].

Currently, imaging of intracranial electrodes in MRI for clinical and research purposes is severely limited by both the potential safety risks and image quality.

During MRI, Radio Frequency magnetic and electrical fields are produced that can couple to the metallic implanted electrodes and lead to a risk of local heating and tissue damage. The exact risk is a complex problem defined by the complex and patient specific implant and RF coil geometry. Importantly, because of this variability it can be treated as a 'worse case', where the findings of this project are likely to be generalizable to most other elongated brain implants. This interaction with the RF fields also locally degrades MRI image quality that relies on a uniform RF magnetic field.

Parallel transmit RF technology has the ability to shape the RF fields and recent work has shown that this can be used produce fields that minimize implant interactions for electrodes with simpler geometric variability [2].
This research project aims to investigate the design of modes of operation utilizing parallel transmit coils at 3T/123MHz and determine how they can be generalized to limit risks of local heating for a wide range of implant configurations. Key to this work will be defining a range of transmit coil designs

and investigating the applicability of the RF fields they generate for this purpose in addition to understanding how critical parallel transmit channel number is to establishing safe operational modes.

Based on this work a prototype parallel transmit coil will be built and tested with realistic test objects to verify that the simulation based safety improvements are realized in-practice. This will use testing with temperature measurements using MRI and temperature probes along with B1-field measurements.

Objective 1) Define the typical range of electrode implantations based on data from multiple sites (where strategies can differ). Create a 'basis set' of simplified models that cover the range of likely implantations.

Objective 2) Design a set of possible RF coil architectures with scalable channel count (2, 8 16, 32). The coil architectures will be based on loop and dipole antenna design using transmit-receive concept.

Objective 3) Determine the modes of operation of the RF coil architecture with factors design and channel count that minimize coupling and maximize B1 magnetic field performance for the range of implantations.

Objective 4) Develop and test a prototype RF coil to the design yielding the best simulated performance.

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Photoacoustic endomicroscopy probe for guiding neurosurgical procedures

Project reference: SIE_27

Start Date: October 2020

First supervisor: Wenfeng Xia

Second supervisor: Hongbin Liu

Project summary: Gliomas are the most common type of brain tumour with a grade-dependent prognosis. Glioblastomas (grade 4) have a 5-year survival rate of only 2%. Accurately determining the tumour grade is crucial to optimise patient outcome. However, grading accuracy with stereotactic biopsies is currently limited by inaccurate tumour sampling. During stereotactic brain tumour biopsy, tissue samples are extracted through a needle guided by preoperative stereotactic CT or magnetic resonance imaging (MRI) scans, which cannot reliably determine the right target points. The excised tissue samples are then sent to pathology for a rapid smear examination (~30 min) to obtain a preliminary diagnosis while the patient is still in the theatre. If the samples are extracted from non-diagnostic regions (e.g. from healthy brain tissue), additional biopsies are taken. Each biopsy involves a certain risk of intracranial haemorrhage for the patient. Additionally, each session of the smear examination increases the risk of infection and the costs of theatre time and pathology. In a study with advanced frameless-electromagnetic-navigated-guided biopsy procedures in 371 patients, non-diagnostic tissue samples were provided in 22 cases; repeat biopsy was performed in 6 cases and adverse events that resulted in clinical compromise were observed in 4 patients. Thus, there is an urgent need for novel intraoperative imaging modalities which can visualise cellular-level pathological changes in real-time to guide tumour biopsies.

Project description: This project aims to develop a highly miniaturised, high-resolution, all-optical photoacoustic imaging probe to obtain molecular and microstructural information of tissue from within a stereotactic biopsy needle, so that it can be used to guide interventions in the neurosurgical suite. Photoacoustic imaging is well suited to visualise changes in vascular morphology and blood oxygenation that are known to be associated with tumour development. We will investigate the potential of this novel miniature multi-modal imaging probe to:

- improve the grading accuracy by preventing the extraction of non-tumour tissues;
- reduce the number of times a biopsy needle needs to pass through the brain, which is associated with the risk of intracranial haemorrhage;
- reduce the theatre time, the risk of infection and the cost of pathology by eliminating the need for the pathological smear examinations.
- facilitate tumour margin assessment during brain tumour resections.

The success of this project will open up new ways to obtain functional, molecular and micro-structure information at cellular level in real-time during minimally invasive procedures across many clinical fields including neurosurgery, oncology, cardiology and fetal medicine.

Objectives

- Photoacoustic endomicroscopy probe development. A novel miniature all-optical photoacoustic endomicroscopy probe that will be integrated within a stereotactic biopsy

needle to acquire functional, molecular and microstructural images from brain tissue during minimally invasive neurosurgical procedures.

- Phantom imaging. The performance of the developed imaging system will be evaluated and optimised with tissue mimicking phantom.

Human tumour tissue imaging. As a first validation step, imaging with the needle probe will be performed in the neurosurgical suite with human brain tissue ex vivo, immediately before it is submitted for histology.

Smart Sensors and Actuators research area

Development of affordable minimally invasive endoscopic surgical tools for resource constrained operating rooms

Project reference: DTP_SIE_14

Start Date: October 2020

First supervisor: Prashant Jha

Second supervisor: Hongbin Liu

Project summary: Five billion people do not have access to safe surgery, two billion have no access at all, and three billion have access to some kind of surgery, but it is not really safe. Lack of surgery and also poor surgical conditions are neglected global health problems affecting the world's poorest people. In LMICs (Lower, Middle-Income Countries), operative mortality is high (5–10%), with the majority related to infections, anaesthesia complications, and haemorrhage.

Project description: It has been shown that, even in low-resource settings, MIS (Minimally Invasive Surgery) would provide many advantages over open surgery, such as decreased risk of infection, decreased blood loss, reduced postoperative pain, improved bed utilization, shorter hospital stay and rapid return to work. These advantages are even more important in low-resource settings where sanitary conditions are poor, blood banks not available and distances to hospitals are large.

Compared to open procedures, the MIS procedure implies many limitations for the surgeon. Long instruments are inserted through a small incision, resulting in limited movement possibilities, and in scaling and mirroring of movements. An endoscope (camera) is inserted presenting a 2D image on the screen. Due to misalignment of the natural line of sight with the camera orientation, misorientation can occur, limiting the ease of manipulation of the instruments. To improve tissue manipulation capabilities, better tip/tissue alignment due to a steering mechanism between tip and shaft is needed as found in e.g. robotic surgery; however, it is not feasible to use complex and expensive robotic master-slave systems in hospitals in LMICs.

We propose to develop a surgical equipment system which will allow minimally invasive surgery without the need for a sterile operating room and will have lesser dependence on operator skills. We will use a human-centric design approach and co-creation involving clinicians, designers, entrepreneurs and engineers to develop easy-to-manufacture, easy-to-use and easy-to-clean instrument. Prototype testing will be done together with clinical groups in South Asia / Africa, (new) spin-off companies and surgical device certification experts. After benchtop/cadaver testing, the developed instruments will be ready for pilot clinical testing.

Interoperable three-dimensional medical device tracking with a fibre-optic ultrasound transmitter

Project reference: DTP_SIE_08

Start Date: October 2020

First supervisor: Wenfeng Xia

Second supervisor: Tom Vercauteren

Project summary: A long-standing problem in minimally invasive procedures guided with ultrasound imaging is the identification of the medical device tip within the body.

Project description: Ultrasonic visualisation of medical devices such as needles can be very challenging when the distal ends are not coincident with the ultrasound (US) imaging plane. This occurs frequently in clinical practice: during “in-plane” insertions, a thin needle can readily stray from the imaging plane; during “out-of-plane” insertions, only a small region of the needle in the vicinity of the imaging plane can be visualised, and in this region, the needle tip can have a very similar appearance to that of the needle shaft. Additionally, medical device visibility can be lost during steep, large-angle insertions, as US waves are reflected away from the US probes. This problem is experienced acutely during percutaneous interventions in many clinical fields, including fetal medicine [1] and neonatology [2]. Serious complications can arise from loss of visibility of the medical device.

We have pioneered the developments of ultrasonic tracking, a technique that is based on ultrasound communication between an external ultrasound imaging probe and a fibre-optic receiver that is integrated within the interventional device. Robust demonstrations of this technology up to large animal models have been published by the team. However, the first-generation system relied on an ultrasound imaging device that can be operated in research mode but provides substandard image quality. Additionally, 3D tracking with this system requires the use of a custom ultrasound probe comprising transducer arrays for both ultrasound imaging and tracking. These limitations make clinical translation of the technology non-straightforward and prevent the use of the technology with state-of-the-art clinical ultrasound imaging systems.

This project aims to develop a new generation 3D tracking system that will address the above-mentioned limitations. It will be based on a tracked fibre-optic ultrasound transmitter and an ultrasound detector with multiple elements attached to an external ultrasound imaging probe. Ultrasound transmissions will be received by the detector and processed to obtain 3D position of the device tip. The positional information will be overlaid on ultrasound images on a second monitor in real-time, separated from that of the ultrasound imaging system. As such, the developed tracking system will be fully compatible with most of clinical ultrasound imaging systems, and therefore hold the potential for widespread clinical use for guiding minimally invasive procedures in many clinical fields. The success of this project will augment research activities for a Wellcome/EPSRC funded project Gift-Surg, and will catalyse new collaborations within the School.

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Intelligent robotic echocardiography

Project reference: DTP_SIE_15

Start Date: October 2020

First supervisor: Kawal Rhode

Second supervisor: Christos Bergeles

Project summary: Cardiovascular disease (CVD) has a significant impact on society in terms of mortality, morbidity and healthcare costs. For example, it causes over 1.9 million deaths in the EU every year (42% of all deaths) with a total estimated cost of £118 billion.

Project description: Medical imaging has a very important role to play in the diagnosis, treatment guidance and follow-up of patients with CVD. Cardiac ultrasound or echocardiography allows real-time visualisation of target heart structures and interventional devices without using ionising radiation. This can be done using a TTE or TOE and is often the first-line imaging modality for CVD. The training and expertise required to perform echocardiography is considerable. This, coupled with the high demand for this type of imaging, means that healthcare providers are becoming increasingly strained to provide this service despite the comparative low cost of the hardware. We have developed a range of robotic ultrasound systems including single- and multiple-arm TTE and TOE. These could have significant impact if they could operate in a highly-autonomous manner with minimal operator input. Artificial intelligence algorithms for dealing with complex inverse kinematics, recognizing standard ultrasound views of organs and analyzing medical image quality have emerged over the recent years. These algorithms could be combined in a closed loop system to develop an intelligent robotic echocardiography system. The challenges are to effectively combine these elements and to validate and test from bench to bedside.

Months 1-3: Literature review and ethics
Review of literature on robotic ultrasound systems, artificial intelligence to solve large DOFs serial chain and flexible robotic inverse kinematics and artificial intelligence to analyze ultrasound image quality. Apply for KCL Research Ethics for a healthy volunteer study on robotic echocardiography.

Months 4-9: AI-driven view classification
Evaluate a CNN for identification of standard 2D cardiac echo views using retrospective data from adult cardiology and/or healthy volunteer data (TTE only for latter). This will be limited to all standard TTE views and approximately 5 TOE views (out of the possible 20). Submit paper 1.

Months 10-15: Open loop robotic steering
Develop and validate AI-based inverse kinematics solutions for our existing ultrasound robots. Validation will be carried out using a target object phantom and EM tracking to determine the accuracy and robustness of the steering.

Months 16-21: Closed loop robotic steering
Couple and validate AI-based view classification with AI-based inverse kinematics. Validate this using an anthropomorphic cardiac phantom. Test this approach using healthy volunteers and single-arm TTE robotic system. Submit paper 2.

Months 22-30: Fine control
Evaluate methods for measuring echo image quality and incorporate into the closed-loop robotic steering. Validate this using an anthropomorphic cardiac phantom. Test this approach using healthy volunteers and single-arm TTE robotic system.

Months 31-36: Extensions & write-up
Possible adaptation to multi-arm or concurrent TTE and TOE systems. Write up thesis. Submit final paper.

Tele-operated robotic thrombectomy in acute stroke

Project reference: DTP_SIE_18

Start Date: October 2020

First supervisor: Thomas Booth

Second supervisor: Kawal Rhode

Project summary: Stroke is the second leading cause of death across the world, annually killing approximately 6 million people and the third leading cause of disability. In England, Wales and Northern Ireland, 85,000 people are hospitalised with stroke each year[2]. Time from onset to treatment is known to be especially critical, with the effectiveness of treatment declining rapidly in the first few hours after stroke[1]. More recently, thrombectomy has shown substantially improved clinical outcomes in patients with large vessel occlusion present in approximately 40% of patients with acute ischaemic stroke[3,4]. Thrombectomy may be effective up to 6 h or more after stroke onset (depending on patient selection) but also demonstrates reducing effect size with increasing time from stroke onset[2]. The proportion of patients eligible for thrombectomy in the UK has been estimated at about 10%[6]. Providing thrombectomy presents a significant challenge for health services. The procedure is typically carried out by a neuro-interventionist.

Project description: Robotically-assisted angiography in the cerebral vasculature has only recently been described by three groups[7,8,9]. For neurointerventional applications, the lack of a platform specifically designed to accommodate very small devices and microcatheters— and the technically demanding “micromovements” required to successfully navigate these tools through the cerebral vasculature — has left neurointerventional robotics virtually unexplored[9]. This is a limitation of the Magellan system which is now no longer commercially available[7].

Two basic mechanisms have been developed to perform robotic surgery in general. Some robotic systems are telemanipulators, which means that they essentially copy the operator’s movements directly. Other systems transform the movements of the operator such that a joystick can manipulate a guidewire or microcatheter[7,8,9]. These systems are motivated by improving the neurointerention procedure itself.

Given that the motivation of this project is to develop tele-operated robotic thrombectomy to allow local treatment to be performed remotely from a specialist neuroscience centre, the emphasis is on the former system i.e. developing robotic systems that are telemanipulators. The key advantage compared to the three systems described above[7,8,9] is that operators would perform tasks in a way that is identical with their current practice with little new learning required (i.e. pushing and rotating catheters and wires as opposed to using a joystick). The large amount of delicate manipulation of the tiny catheter (2.1 Fr) and wire (0.014 inch) that occurs during the procedure demand that a major focus of the project would be on haptic feedback which is a major concern in the current joystick-controlled systems[7,8,9].

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Bioinspired fluidic sensing and actuating for soft endoscopic robots

Project reference: SIE_21

Start Date: October 2020

First supervisor: Hongbin Liu

Second supervisor: Wenfeng Xia

Project summary: Endoscopy has seen its overall demand double in the UK over the last five years. Hospitals will soon be unable to meet the growing demand with existing technology which has not changed fundamentally over the last 60 years. To meet this challenge, we have been dedicating our efforts to investigating new robotic endoscope technologies which enable quick, safe and effective endoscopic procedures in the least invasive way possible. Inspired by nature, we developed a novel ultra-flexible robotic endoscope. It is made of soft material and actuated with biocompatible fluid, and can significantly improve the safety and comfortableness of endoscopy compared to existing solutions. This project aims to develop novel technique to enable real-time sensing of the forces applied to the soft endoscope as well as the shape of the endoscope precisely, providing clinicians vital information to enhance safety and efficiency of endoscopic procedures.

Project description: Endoscopy has seen its overall demand double in the UK over the last five years. Hospitals will soon be unable to meet the growing demand with existing technology which has not changed fundamentally over the last 60 years. To meet this challenge, we have been dedicating our efforts to create new robotic endoscope technology to carry out endoscopic procedure safely and effectively in the least invasive way possible. Our lab developed a soft robotic colonoscope, MorphGI, which is an ultra-flexible colonoscope. It can be guided through the colon safely with minimal effort from the clinician and is capable of completing a safe and painless procedure. This system has significant advantages over existing solutions in terms of cost effectiveness, robustness and procedure time and is the first device which can self-propel in torturous, compliant and not entirely cleaned digestive tract.

This project aims to develop a novel technique to enable real-time sensing of the forces applied to the MorphGI as well as its shape precisely. Since MorphGI endoscope is made of soft material and actuated by hydraulic fluid, the focus of the research is on how to use the actuation fluid as the sensing medium to achieve the above goal without invading the ultra flexibility of the device. Studies will be carried out to explore how to design and model the actuation channels in order to use the hydraulic actuation forces to intrinsically detect and estimate static contact forces with the environment. Furthermore, research will be carried out to understand how hydraulic actuation forces and volumetric flow can be used to detect and estimate the changes in the endoscope shape due to external forces. Activities including design of actuation chamber, soft material modelling in combination with fluid mechanics, dynamics will be investigated to gain theoretical understanding of above question. Finite Element Modelling and other analytical methods will be considered. Innovate fluid sensing mechanism, such as using conductive fluid, and new fabrication methods will be investigated to advance technology frontier of this field.

The sensing technology to be developed from this project is applicable to numerous endoscopic procedures ranging from gastroenterology to airway management. It will be evaluated by the leading clinicians from Guys St Thomas Hospitals and King's College Hospitals.

Development of a flexible microrobotic solution for Early Breast Cancer Diagnosis

Project reference: SIE_22

Start Date: October 2020

First supervisor: Christos Bergeles

Second supervisor: Sebastien Ourselin

Project summary: We aim to develop "MAMMOBOT" for early detection of breast cancer. MAMMOBOT is a flexible steerable growing endoscopic robotic system that can safely navigate the mammary ducts, and harness imaging and sensing technologies to provide local cellular-level diagnosis. Beyond early detection, MAMMOBOT provides a novel platform for minimally invasive local therapies delivered directly to mammary duct disease. The end-goal is an integrated platform that incorporates proof-of-concept for the millimeter-scale growing robot, developed through this PhD project, and navigation algorithm, and deployed sensor array developed through our collaborators at Imperial, Leeds, Bath, and University of Edinburgh.

Project description:

Clinical Need. There are over 55,000 breast cancers diagnosed per year in the UK alone. "Early breast cancer" refers to detection of small invasive and non-invasive cancers such as ductal carcinoma in situ (DCIS). However, many "early" breast cancers require surgery, radiotherapy and chemotherapy at UK prevalent costs that reach close to £430m. Arguably, there needs to be a re-framing of what constitutes "early" breast cancer with platforms for detecting and excluding the disease and its precursors at far earlier time-points, so as to increase survival rates and reduce morbidity associated with current treatments. Given its ductal origins, a robotic framework that enables navigation, interrogation and intervention within the ductal network via access through the natural orifice of the nipple could completely disrupt the way in which breast cancer is diagnosed and treated.

Ductoscopic Technology Development. Mammary ductoscopy has shown tremendous promise as a vehicle for early diagnosis excluding breast cancer in patients with cancer precursors. Despite its potential, the technique has not been widely adopted in the UK, simply because current platforms are unwieldy, inflexible, and cannot safely, swiftly and smoothly navigate down the complex tree-like structure of the mammary ducts. Robotics can overcome the inherent challenges faced by the human operator, and more precisely manipulate and articulate endoscopes at scale. This project pertains to developing the robotic platform for safe ductoscopy, while additional elements will be contributed by our collaborators at Imperial College London, and Universities of Bath, Leeds and Edinburgh.

Proposed Robotic Technology. Growing robots can "unfold" inside the mammary ducts via addition of material at their tip, and therefore minimise disruption of the anatomy. Robotic catheters, on the other hand, rely on insertion through pushing, implying harmful frictional forces between the catheter and duct. This safety characteristic of growing robots matches the project's needs for moving within the breast ducts (1-8mm) with minimal collateral damage. The different aspects of the project are as follows:

Front End: We will create a 3-chamber flexible growing robot of 1-2mm diameter. Each of the 3 chambers will be independently addressable for steerability and growing. Hydraulic pressure within each chamber would cause the unfolding of new material from the front of the respective chamber, and therefore elongation along a desired trajectory.

Back End: We will develop appropriate actuation for the flexible growing robot and manipulation of chip-on-tip cameras. For robot chamber control, independent hydraulic circuits to control the pressure of microfluidic pumps. A force-controlled winch will ensure that the encapsulated camera sensor will be in the appropriate location with respect to the growing body of the robot.

Robot Control: We will develop hydraulic controllers optimised for micro flows, using reduced order models of growing robots based on soft robotics theory. We will use the TMTDyn package, co-developed by the Robotics and Vision in Medicine (RViM) Lab.

Risk Mitigation: To ensure the project's goal for robotic mammary duct exploration is met, we will in parallel use existing flexible (1mm diameter) robots based on concentric tube technology. Their surfaces will be micromachined to ensure robot stiffness reduction and maximum compliance with delicate tissue.

Artificial Smart Valve for Bag-Free Stoma

Project reference: SIE_24

Start Date: October 2020

First supervisor: Sebastien Ourselin

Second supervisor: Carlo Seneci

Project summary: Living with a stoma, a small opening on the abdomen where the remaining healthy portion of bowel is connected to release the stool, represents a great physical and mental challenge for the hundreds of thousands of patients living with one. On one hand, often, stoma forming surgery represents the only survival chance for patients. On the other hand, the everyday management of the stoma is usually characterised by a large number of inconveniences and problems, such as infections, skin blistering, stool leakage, bad odour, difficulty with sports and sexual life. The aim of this project is to deliver an implantable smart device, the first of its kind, that helps stoma patients tackle the challenges deriving from stoma management and allowing them to carry out the same activities and routines that they would be having prior to stoma surgery. The implant will feature a combination of flexible and hard materials, sensors and actuators to make stoma management easier and bag-free. This research work will be carried out with the input from patient groups and the support of surgical and nursing experts. To carry out the work, the PhD student will perform CAD design, biomechanical modelling, simulation, 3d printing, moulding and programming.

Project description: Pathologies affecting the bowel are numerous and varying in nature, and often require surgical treatment. It is estimated that every year in the UK about 13,000 patients undergo surgeries that result in a stoma, such as colostomy and ileostomy surgery. These surgeries are performed when the patient loses temporarily or permanently the functionality of a portion of bowel, therefore requiring an alternative stool-excretion way. A stoma is a non-sealed opening created on the patient's abdomen where the remaining healthy portion of the bowel or colon is attached to the abdominal wall to allow for the excretion of stool in a stoma bag that is taped to the patient's abdomen. The prospect of such disruptive change in life for patients can be overwhelming; many patients prefer to avoid stoma forming surgery, even if that results in reduced lifespan. Patients that elect to undertake the surgery constantly deal with the psychological burden deriving from an external stoma bag, bad odours and frequent leakage. Sport and sexual life also can result hindered. Most importantly, the stoma bags are attached with tape that causes skin blistering and moreover, increases the risk of infection.

Worldwide, industry and academia have invested substantial resources in the research of new technologies and solutions to provide prosthetics with additional functionalities, such as motion control and sensory feedback for prosthetic limbs. Unfortunately, not much effort has been devoted to assisting these sufferers, and virtually no progress has been made to improve their condition and their quality of life.

The proposed project aims to develop an implantable device that enables creating a stoma that has a lower risk of infection as the bowel tissue is not exposed to the exterior of the body, while allowing for stool storage within the body (no need for stoma bags, nor tape) thanks to surgical techniques similar to already performed ones such as J-loop or S-loop ileostomy. Furthermore, a flexible

controllable valve will be mounted within the implant to allow the patient to directly control the valve and allowing them to regain control of their bowel. The flexible portion of the valve will also carry a patch that will seamlessly cover the stoma valve, rendering this device also aesthetically appealing. Other limitations that we are able to address with our device are the possibility to willingly release gas when more appropriate and the valve will also feature easy cleaning to avoid odours. Furthermore, the use of smart sensing that will be embedded in the flexible valve will allow for direct data collection regarding the condition of the stoma to help managing it and predict possible issues that can be prevented, such as ph, temperature, pressure, etc. In a similar way, an embedded actuator will also be deployed to complete the device with all its functionalities and that will allow the patient to release the stool without even touching the valve itself.

To reduce the risk in addressing all these challenges, a gradual approach will be followed:

- Year 1: Implant and valve design and construction, with consideration on the surgical technique and the science behind the materials used and biocompatibility. The valve will be directly actuated by the patient's hand.
- Year 2: Design and construction of smart sensors array to measure: pressure, stool presence, ph and temperature.
- Year 3: The final year will focus on the full system integration and on bench and ex-vivo testing of the device using phantoms and animal models. This will allow for reviewing and improving all the aspects of the device for the project completion.