Project 1: Mixed Reality Visualisation for Surgical Guidance

Dr Stamatia (Matina) Giannarou, Haozheng Xu, Joseph Davids

Aims and objectives

In this project, a novel application of the latest holographic technologies such as the HoloLens, will be explored to design a mixed reality visualisation platform to provide intraoperative surgical guidance during the execution of challenging surgical tasks. The project will focus of the positioning of surgical instruments such as needles and cannulas during arterial and lumbar puncture.

Background

In the last decade, there has been a great effort to bring mixed reality (MR) into the operating room to assist surgeons intraoperatively. However, progress towards this goal is still at an early stage. Using the HoloLens, previous research has mainly focused on projecting a virtual 3D model into a patient's body [Pratt] or just above it to avoid obstructing a surgeon's line of sight. This allows the surgeon to perform surgery while visualising a virtual 3D object. Recently, a MR visualisation platform has been developed to assist in intraoperative surgical guidance by projecting multiple imaging modalities simultaneously using both 2D screens and 3D virtual objects [Cartucho]. However, the previous studies focused on the visualisation of multimodal data without providing guidance to assist surgical task execution. The proposed project will develop a MR platform which provides live streaming of intraoperative data and virtual objects to assist the execution of challenging surgical tasks. A key application is the positioning of surgical instruments such as needles and cannulas during arterial and lumbar puncture. The versatile nature of this platform makes it suitable for various other surgical tasks such as visual servoing.

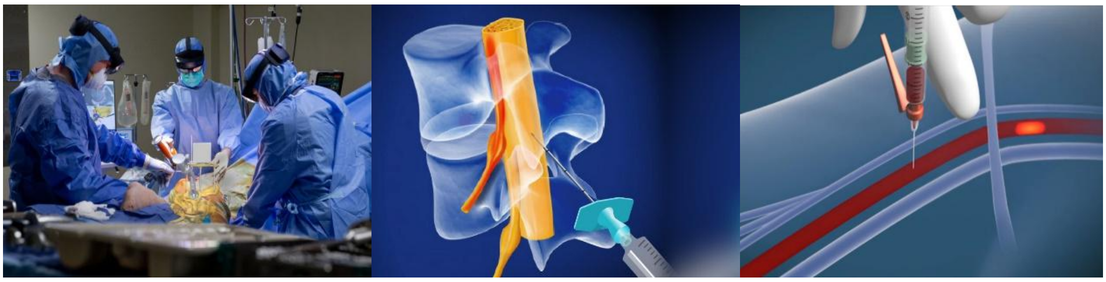


Figure: Mixed Reality visualisation in lumbar and arterial puncture.

Skeleton project plan

The project will proceed largely as follows, bearing in mind that several of the tasks can be completed in parallel:

- A holographic model of the surgical phantom will be generated;
- The 3D structure of the anatomy will be used to create virtual objects to indicate the optimal pose of surgical instruments;
- Virtual objects will show intraoperative data streamed live to the surgeon;
- Accuracy and operator usability will be used as outcome measures for the project.

Hardware/software requirements

Matlab / Python / Unity, HoloLens, Surgical phantoms

References

[Pratt] Pratt P, Ives M, Lawton G, Simmons J, Radev N, Spyropoulou L, Amiras D, "Through the hololens' looking glass: augmented reality for extremity reconstruction surgery using 3d vascular models with perforating vessels". Eur Radiol Exp 2(1):2 (2018)

[Cartucho] João Cartucho, David Shapira, Hutan Ashrafian, Stamatia Giannarou, "Multimodal mixed reality visualisation for intraoperative surgical guidance". Int. J. Comput. Assist. Radiol. Surg. 15(5): 819-826 (2020)

Project 2: Microscopic visual servoing for autonomous robotic tissue scanning

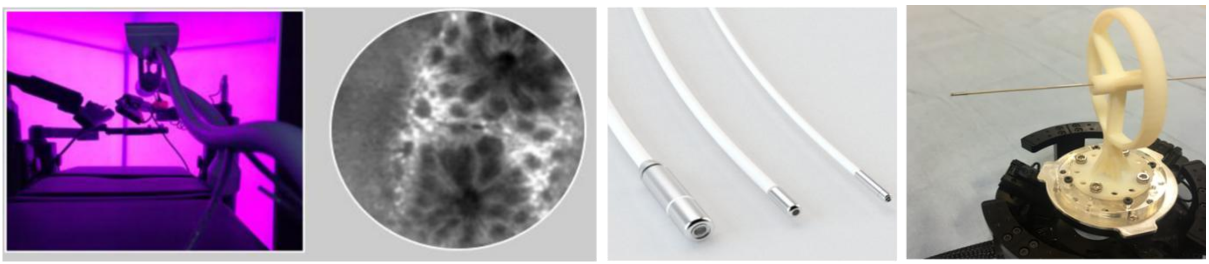
Dr Stamatia (Matina) Giannarou, Chi Xu, Alfie Roddan, Joseph Davids

Aims and objectives

In this project, a microscopic visual servoing framework will be designed to provide quality optimisation of endomicroscopic information during robotic tissue scanning. This will facilitate in vivo, in situ tissue characterisation and guide autonomous robotic tissue scanning to focus locally on pathological areas, during robotically assisted operations. A key application of this system is the accurate tumour margin delineation in neurosurgery.

Background

Biophotonics techniques such as probe-based Confocal Laser Endomicroscopy (pCLE) have enabled direct visualisation of tissue at a microscopic level, with recent pilot studies suggesting it may have a role in identifying residual cancer tissue and improving resection rates of brain tumours. Recently, robotically controlled local tissue scanning with pCLE probes has been investigated to facilitate diagnosis providing image stabilisation and field-of-view (FOV) expansion based on image mosaicking. However, the interpretation of endomicroscopic information remains challenging, particularly for surgeons who do not themselves routinely review histopathology. The main challenges to such tissue characterisation are due to the fact that the quality of the pCLE data is prone to degradation during scanning due to debris on the tissue surface or motion instability of the imaging probe. In this project, a visual servoing framework will be designed to optimise the quality of pCLE data during robotic tissue scanning [Xu]. A deep learning model will be used to evaluate the distance between the pCLE imaging probe and the tissue surface to guide the longitudinal translation of the imaging probe with respect to the tissue surface. For precise positioning, a 6 DOF parallel robots SMARPOD 110.45.1-D-S produced by SmarAct will be used.



(a) (b) (c) (d)

Figure: (a) Robotic tissue scanning (b) Endomicroscopic image (c) Cellvizio pCLE imaging probes (d) Parallel robot for precise tissue scanning.

Skeleton project plan

The project will proceed largely as follows, bearing in mind that several of the tasks can be completed in parallel:

- pCLE video data and probe-tissue distance data collection;
- Deep learning-based probe-tissue distance estimation;
- Robotic control for autonomous longitudinal translation of the imaging probe with respect to the tissue surface.

Hardware/software requirements

- Matlab / C++/ Python
- Cellvizio, Mauna Kea Technologies
- Robotic pCLE tool

References

[Xu] C. Xu, A. Roddan, J. D Davids, A. Weld, H. Xu, and S. Giannarou, "Deep Regression with Spatial-Frequency Feature Coupling and Image Synthesis for Robot-Assisted Endomicroscopy", MICCAI 2022

Project 3: Robotic guidance and localisation during endoluminal procedures

Dr Stamatia (Matina) Giannarou, Mr Dan Leff

Aims and objectives

In this project, a robot localisation framework will be designed to assist navigation during endoscopic examinations of complex anatomical structures such as the ductal tree. This will facilitate thorough endoscopic examinations targeting and retargeting of pathological sites and the deployment of sensing probes for in-vivo, in-situ tissue characterisation.

Background

Small invasive and non-invasive cancers such as ductal carcinoma in situ, referred to as "early" breast cancers still require surgery, chemotherapy and radiotherapy at substantial human and financial costs. Early breast cancer detection requires to detect the disease internally via systematic integration of the mammary duct network. Conventional ductoscopy has failed to penetrate practice as systems are unwieldy and inflexible. However, a flexible robotic system that can safely and reliably navigate the mammary tree has potential to disrupt breast cancer diagnosis and treatment. This project is part of a CRUK research grant aiming to develop the MAMMOBOT, a flexible steerable endoscopic robotic system that can safely navigate the mammary ducts, and harnesses novel sensors to highlight global duct abnormalities and imaging technologies to make local microscopic diagnoses. The project will focus on robot localisation and guidance which are essential for thoroughly examining the ductal tree, targeting and retargeting pathological sites and deploying sensing probes in-vivo while keeping optimal tissue contact. To facilitate surgical guidance, morphological structures need to be integrated with sensing data to provide intraoperative augmented reality visualisation. A robust robot localisation system will be developed based on the matching of ductoscopic data with virtual camera views from a patient-specific ductal tree model. Surface shading will be used to recover geometric information from ductoscopic images. The robot will be localised in the ductal tree by maximising the similarity between video images to the virtual camera views considering both shape and temporal information. Deep learning approaches will also be explored to map endoscopic video data to camera pose.

Figure: (a) Ductal tree (b) Endoscopic view of the tree model (c) Localisation inside the ductal tree.

Skeleton project plan

The project will proceed largely as follows, bearing in mind that several of the tasks can be completed in parallel:

Collection of endoscopic data;
Building of a video database with corresponding 3D model data;
Depth estimation and extraction of structural characteristics for robot localisation.

Hardware/software requirements

Matlab / C++/ Python, Ductoscope, endoscope, Ductal/bronchial tree phantoms

References

[Shen] M Shen, S Giannarou, PL Shah, GZ Yang , "Branch: Bifurcation recognition for airway navigation based on structural characteristics", MICCAI 2017

Project 4: Surgical Vision Using Structured Light to Create Surgical Scenes with Known 3D Structure

Dr Stamatia (Matina) Giannarou, Alistair Weld, Baoru Huang

Aims and objectives

The goal of this project is to capture surgical scenes using endoscopic cameras and use structure light to recover their 3D structure. This will result in the generation of a database with videos of surgical scenes, projections of structured light patterns and ground truth depth information. A key application of this database is the training and benchmarking of computer vision methods for surgical navigation.

Background

Surgical robots rely on robust and efficient computer vision algorithms to be able to intervene in real-time. The main problem, however, is that the training or testing of such algorithms, especially when using deep learning techniques, requires large endoscopic datasets which are challenging to obtain, since they require expensive hardware, ethical approvals, patient consent and access to hospitals. Recently, we tackled this problem by developing VisionBlender [1], an open-source solution to efficiently generate large and accurate synthetic endoscopic datasets. To further improve our solution, our goal now is to create 3D surgical scenes using endoscopic cameras and structured light pattern projectors. The generated dataset will be used to validate and possibly advance, state-of-the-art depth estimation methods based on deep learning including our recent model for disparity estimation [2].

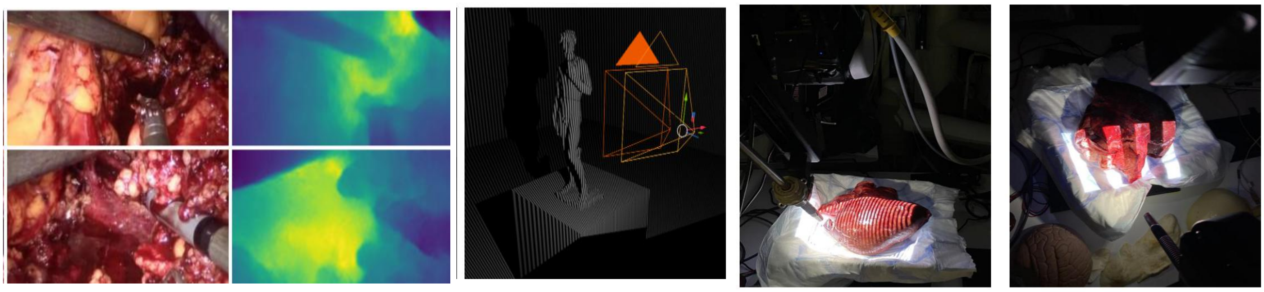


Figure: (Left) In vivo surgical scenes with depth reconstruction maps. Projected structure light patterns for 3D reconstruction on (Middle) virtual and (Right) medical scenes.

Skeleton project plan

In this project you will:

1) Record phantom and ex-vivo scenes using an endoscopic camera and a structured light projector
2) Generating ground truth depth maps using computer vision and the projected pattern maps
3) Apply and validate depth estimation methods developed at the Hamlyn Centre and in the literature

Hardware/software requirements

Python/C++, Surgical phantoms, Ex vivo organs

References

[1] J. Cartucho, S. Tukra, Y. Li, D. S. Elson, S. Giannarou, "VisionBlender: A Tool to Efficiently Generate Computer Vision Datasets for Robotic Surgery", Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, 2020. https://github.com/Cartucho/vision_blender

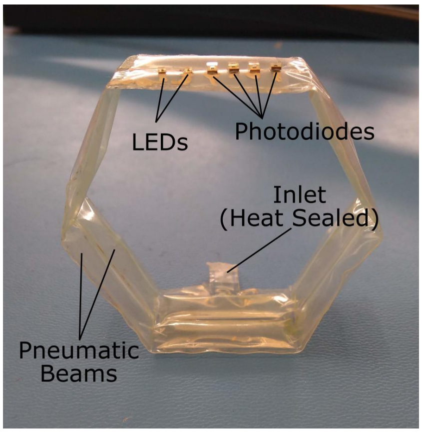
[2] Alistair Weld and Joao Cartucho and Chi Xu and Stamatia Giannarou, "Regularizing disparity estimation via multi task learning with structured light reconstruction", Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, 2022

Project 5: Developing implantable, inflatable optical oxygenation sensors

Dr Alex Thompson, Dr James Avery, Ms Elena Monfort Sanchez, Dr Mark Runciman

Aims and objectives

The aim of this project is to design and fabricate an optical oxygenation sensor based on diffuse reflectance spectroscopy and soft robotics.



Background

Soft robotics offers wide-ranging opportunities to enhance minimally invasive surgery through the production of robotic tools that can move within the body without damaging surrounding tissues (e.g. [1]). Optical sensing – for example, based on reflectance and fluorescence spectroscopy – allows interrogation of tissues *in vivo* and provides the ability to measure important tissue properties such as oxygenation and metabolic status [2]. Thus, incorporating optical sensing capabilities into soft robotic platforms may afford a range of new opportunities for surgery and early diagnostics (e.g. [3]).

Project overview

The main objective of this project is to design an optical sensor suitable for oxygenation monitoring in colorectal tumours. The setup of the sensing electronics (e.g. LEDs and photodiodes) will first be designed through simulations of the optical signals expected in intestinal tissue. Following simulations and device design, the sensing electronics will be assembled and controlled using an Arduino kit and prototype soft inflatable sensors will then be developed (e.g. wearable soft cuff, implantable ring, etc.) by incorporating the electronics into inflatable soft robotic scaffolds. At this stage, a series of materials will be tested and a number of fabrication protocols will also be assessed for integration of electronics into the robotic scaffolds.

Skeleton project plan

1. Simulations of optical signals in intestinal tissue using TOAST++ [4] including identification of optimal LED-photodiode separation and investigation of impact of scar tissue
2. Assembly and control of optical sensing electronics using Arduino kit
3. Testing and optimisation of materials and fabrication techniques for soft inflatable scaffolds (e.g. laser welding, silicon moulding, MicroFab inkjet printing, etc.)
4. Integrate optical sensing components (LEDs, photodetectors, optical filters, etc.) into the soft robotic platform based on the optimised fabrication protocol
5. Produce demonstration smart sensing soft robot with optical sensing capabilities

Hardware/software requirements

- SolidWorks or other CAD software
- Laser welding and silicon moulding/curing for soft inflatables
- MicroFab inkjet printing
- LEDs, photodetectors, electronic components (Arduino)
- MATLAB for data analysis and simulations

References

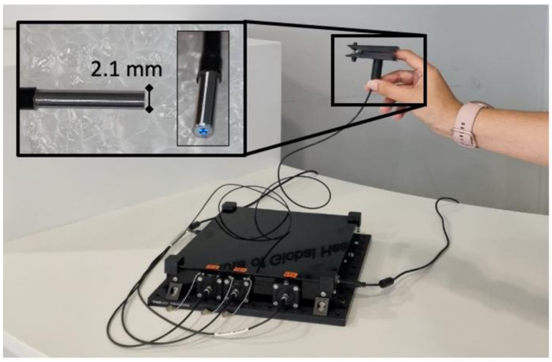
1. M. Runciman, A. Darzi, G. Mylonas, “Soft Robotics in Minimally Invasive Surgery,” *Soft Robotics* 6(4), DOI: https://doi.org/10.1089/soro.2018.0136, (2019)
2. A. J. Thompson, G.-Z. Yang, “Tethered and Implantable Optical Sensors,” in: *Implantable Sensors and Systems*, editor: G.-Z. Yang, Springer, Cham, (2018)
3. J. Avery, M. Runciman, A. J. Thompson, G. Mylonas, A. Darzi, "Towards Smart Oxygenation Sensing Implants using Soft Robotics and Diffuse Reflectance Spectroscopy," in *12th Hamlyn Symposium on Medical Robotics*, pages: 61-62, London, UK, (2019)
4. M. Schweiger and S. R. Arridge, “The Toast++ software suite for forward and inverse modeling in optical tomography,” *J. Biomed. Opt.* 19(4), 040801, DOI: https://doi.org/10.1117/1.JBO.19.4.040801, (2014)

Project 6: Wearable fluorescence sensors for non-invasive assessment of gut function

Dr Alex Thompson, Ms Elena Monfort Sanchez, Dr James Avery, Dr Nilanjan Mandal

Aims and objectives

The aim of this project is to design and develop a wearable sensor and sensing protocol for non-invasive monitoring of gut health based on the detection of orally ingested fluorescent dyes through the skin.



Background

Increased gut permeability – often referred to as 'leaky gut' – manifests in a range of health disorders prevalent in both developed and developing countries. These include coeliac disease, inflammatory bowel disease, colorectal cancer, sepsis, HIV and malnutrition. Importantly, the role of increased permeability in many of these diseases is not well understood and the techniques currently used to assess permeability are either highly invasive or unreliable [1]. As such, there is a clear need for new technologies for improved monitoring. An alternative method for quantification of gut permeability has recently been reported, in which orally administered fluorescent dyes are detected in the blood stream using fluorescence spectroscopy [2]. This provides an indication of the degree to which the fluorescent dyes have leaked through the intestinal barrier into the blood.

Project overview

The key objectives of this project are: (i) to design and develop wearable sensors capable of detecting fluorescent dyes using non-invasive, transcutaneous measurements (i.e. by detecting fluorescence through the skin, as described in [2-4]); and (ii) to develop and optimise diagnostic algorithms based on transcutaneous fluorescence data (using existing data collected in an ongoing clinical trial). This technique will improve on the current state-of-the-art in a number of ways: it will be non-invasive, it will not require collection of urine/blood samples, it will provide continuous measurements and will allow rapid dissemination of results. In this project, the students will focus on miniaturisation of the technology and development of diagnostic algorithms, both of which are crucial to facilitate wider clinical use.

Skeleton project plan

1. Assembly and control of optical sensing electronics (LEDs, photodiodes, etc.) using Arduino kit, including integration of pulse oximetry sensing for normalisation/correction of fluorescence data
2. Design, fabrication and testing of sensor embodiments (e.g. finger clip, wrist strap, ear clip, etc.) using CAD software and 3D printing (including integration of sensor electronics)
3. Investigation of optimal data analysis procedures for extraction of diagnostic information
4. Investigation of diagnostic capabilities (i.e. sensitivity, specificity, etc.) in inflammatory bowel disease
5. Project extension: design/development of custom circuit boards for control of sensing electronics

Hardware/software requirements

- LEDs, photodetectors, electronic components (Arduino)
- SolidWorks (or other CAD software) and 3D printing
- MATLAB/Python/LabVIEW/C++ for data analysis and diagnostic algorithm development

References

1. E. M. M. Quigley, *Current Opinion in Gastroenterology*, **32**(2), 74-79, DOI: https://doi.org/10.1097/MOG.0000000000000243, (2016)
2. J. Maurice et al., *Scientific Reports*, **10**, 16169, DOI: https://doi.org/10.1038/s41598-020-73149-2, (2020)
3. A. M. Lett et al., *Biomedical Optics Express*, **12**(7), 4249-4264, DOI: https://doi.org/10.1364/BOE.424252, (2021)
4. E. Monfort Sanchez et al., *Biophotonics Congress: Biomedical Optics 2022,* DOI: https://doi.org/10.1364/TRANSLATIONAL.2022.TS2B.6, (2022)

Project 7: Development of a multi-sensing optical probe for tumour margin mapping in the brain

Dr Alex Thompson, Dr Stamatia (Matina) Giannarou, Dr Joe Davids, Mr Alfie Roddan

Aims and objectives

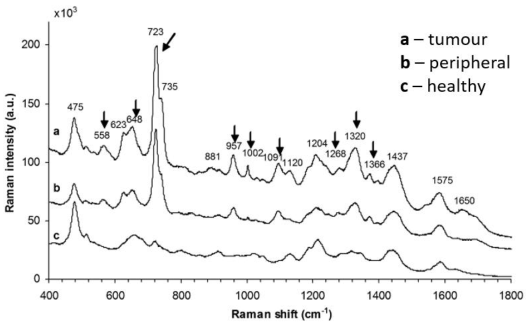
The aim of this project is to develop a system for simultaneous measurement of confocal endomicroscopy images and Raman spectra to allow rapid and accurate mapping of tumour margins.

Background

Glioblastoma is an aggressive form of cancer that is found in the brain or spinal cord. Despite progress in treatments and surgical techniques, survival remains low and is strongly dependent on the ability of the surgeon to successfully and safely resect the entire tumour without damaging surrounding areas of the brain [1, 2]. Tools that provide advanced visualisation/mapping of the tumour margin would therefore be hugely beneficial in improving survival outcomes. A number of biophotonics technologies have been proposed for this purpose due to their ability to provide tissue information in a minimally invasive and non-destructive manner. In particular, confocal endomicroscopy (CE) has been used to visualise tissue morphology at the cellular scale and Raman spectroscopy has been used to assess biochemical signatures of tissues. Both have been applied for assessment/diagnosis of cancer (e.g. [3, 4]) and, importantly, the information provided by the two modalities is complementary (i.e. structural vs. biochemical information).

Project overview

This project aims to develop a system for simultaneous scanning of tissue with both CE and Raman spectroscopy. The students will first design and fabricate a combined mounting system for CE and Raman spectroscopy probes, which will be suitable for integration with minimally invasive robotic scanning systems. They will then use this system to collect combined Raman/CE data from exemplar samples using manual and/or automated scanning stages. The combined Raman/CE data will then be analysed to produce dual-data maps of the sample surface. Finally, if time allows, the students will integrate their Raman/CE mounted probe with a surgical robotic system (e.g. Da Vinci) to demonstrate robotic scanning of samples with dual Raman/CE data acquisition.



Skeleton project plan

1. Design and fabricate a small mounting system for Raman and CE probes using CAD and 3D printing
2. Development of software and experimental setup for simultaneous data collection using combined Raman/CE system
3. Combined Raman/CE data acquisition using manual and/or automated scanning stages
4. Analysis, registration and mapping of Raman and CE datasets to generate 2D, 'dual-data' maps
5. Possible extension: integration of Raman/CE probe with Da Vinci robot for robotic scanning of samples

Hardware/software requirements

- SolidWorks (or other CAD software)
- 3D printing
- MATLAB/LabVIEW/etc. for control of combined Raman/CE data collection
- MATLAB/LabVIEW/C++/etc. for image/data registration and generation of dual-data maps

References

1. Y. Esquenazi et al., *Neurosurgery*, **81**(2), 275-288, DOI: 10.1093/neuros/nyw174, (2017)

2. J. Coburger et al., *Journal of Neurosurgical Sciences*, **61**(3), 233-244, DOI: 10.23736/S0390-5616.16.03284-7, (2017)
3. A. H. Zehri et al., *Surgical Neurology International*, **5**, 60, DOI: 10.4103/2152-7806.131638, (2014)
4. O. Aydin et al., *Applied Spectroscopy,* **63**(10), 1095-1100, DOI: 10.1366/000370209789553219, (2009)

Project 8: Automatic threading of surgical soft robots

Dr Arnau Garriga-Casanovas, Emilia Zari, Prof Ferdinando Rodriguez y Baena

Aims and objectives

The aim of this project is to create a machine that can automatically and precisely add threading needed to manufacture soft robots. The machine needs to be able to achieve high consistency so that the robots have consistent performance. Creating the machine will involve mechanical design, mechatronics, manufacturing, ingenuity, and potentially some computer vision.

Background

Soft robotic manipulators show promise in endoluminal surgery. MiM lab has created a new soft robotic manipulator design that offers higher force than competitors, and offers features close to those needed for endoluminal surgery. We have been able to create a prototype of the robot shown in the image below, but the fabrication method is currently manual, and that creates significant variability. This means that the manufactured robots show significant performance variation, which is undesirable for testing and product development, and also creates a lot of uncertainty for control. The source of the manufacturing problem is adding helical fibres on the outer structure of the robot, which is currently done manually. There is a need for a machine that can automatically add the fibres with any desired pitch, direction, and a consistent selected tension, achieving a high level of precision and consistency.

Figure: Soft robotic manipulator, initial prototype.

Skeleton project plan

The project will proceed largely as follows, bearing in mind that several of the tasks can be completed in parallel:

We will design a machine combining a linear stage and a rotational stage (similar to a lathe machine);
We will develop the control of the machine actuators using a microcontroller and small PCB;
We will investigate ways to control thread tension and implement these with testing and iteration;
We will assemble design, electronics, and tension control and test assembly;
We may add a camera to do quality control on the fly and adjust the motors to keep a good threading

Hardware/software requirements

Solidworks / C# (or other language to program microcontrollers) / Mechatronics / Mechanical testing / Computer vision and AI (potentially)

Project 9: Soft Optical Tactile Sensor to Localise and Assess Colorectal Tumours

Dr James Avery, Ms Elena Monfort Sanchez, Dr Mark Runciman, Dr George Mylonas

Background

Rectal cancer is one of the most common cancers in the world, with over a million new cases diagnosed annually. Assessment of elastic properties of a colorectal tissue has been shown to offer potential improvements to tumour diagnostic accuracy, and detection of precancerous polyps not visible through endoscopic imaging [1]. Providing the surgeon a sense of touch through tactile sensors is an active area of research [2], but currently no device is capable of providing endoscopic assessment of colorectal tumours. The aim of this project is to investigate the feasibility of incorporating tactile sensing into an endoscope balloon which obtains information of the elastic properties of the tissue by sensing the shape of the balloon as it is deformed during contact.

Project overview

In this project the students will create a soft optical tactile sensor capable of measuring the shape of an endoscope balloon, through tracking the size and displacement of a known dot pattern, similar to TacTip soft sensors [3]. Initially, the computer vision algorithm and balloon design will be optimised using a benchtop imaging system and compared to other position tracking methods. Next the system will be integrated into a replica endoscope balloon using miniature cameras (Adafruit Pi Spy Camera or similar). The device will then be tested in phantom experiments, mimicking the colon wall with regions of higher stiffness to represent tumours.

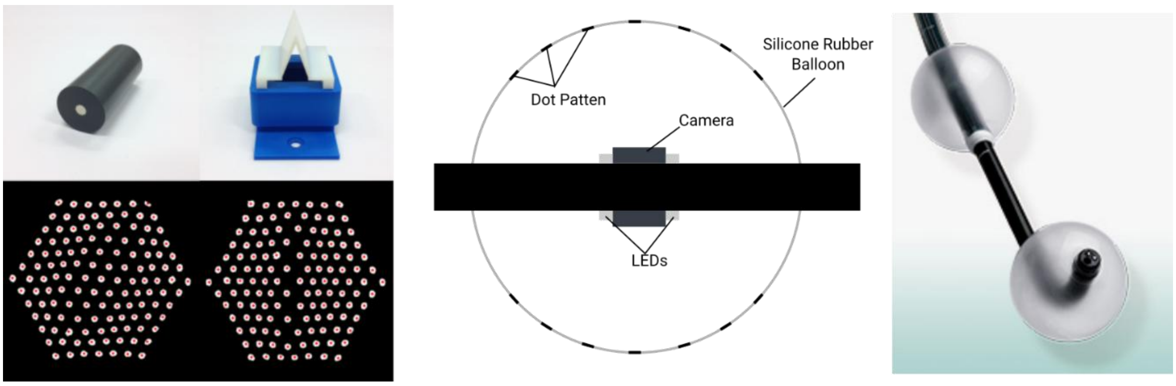


Figure 1 (Left) TacTip sensor concept, deformation of dot pattern resulting from contact with different objects [1] (Right) Example embodiment of optical sensor to track the inflation and deformation of endoscope balloon

Skeleton project plan

1. Develop computer vision algorithm to detect location and size of dot pattern on balloon wall and compare against external sensor (OptiTrack/RealSense)
2. Integrate imaging sensors into endoscopic balloon and optimise dot pattern
3. Perform experiments with tumour phantom to determine if elastic tissue properties can be determined

Hardware/software requirements

- Computer vision – OpenCV or similar
- SolidWorks or other CAD software
- Silicone Rubber (PDMS) moulding
- MATLAB/Python/other software for data analysis

References

[1] S. Kawano *et al.*, "Assessment of elasticity of colorectal cancer tissue, clinical utility, pathological and phenotypical relevance," *Cancer Sci.*, vol. 106, no. 9, pp. 1232–1239, 2015, doi: 10.1111/cas.12720.
[2] P. Puangmali, K. Althoefer, L. D. Seneviratne, D. Murphy, and P. Dasgupta, "State-of-the-art in force and tactile sensing for minimally invasive surgery," *IEEE Sens. J.*, vol. 8, no. 4, pp. 371–380, 2008, doi: 10.1109/JSEN.2008.917481.
[3] B. Ward-Cherrier *et al.*, "The TacTip Family: Soft Optical Tactile Sensors with 3D-Printed Biomimetic Morphologies," *Soft Robot.*, vol. 5, no. 2, pp. 216–227, 2018, doi: 10.1089/soro.2017.0052.

Project 10: Soft Palpation Sensor for Early Detection of Colorectal Tumours

Dr James Avery, Dr Mark Runciman, Amirhosein Alian and Dr George Mylonas

Aims and objectives

The aim of this project is to develop a soft inflatable sensor for detecting pathological abnormalities from an early onset of colorectal cancer.

Background

Over half of 42,000 new cases of colorectal cancer diagnosed each year in the UK are detected at a late stage. The detection of cancerous tissue is mainly done via visual inspection during endoscopy. However, at the early stages, the pathological tissue is not visually distinguishable and is not easily visualised with conventional methods [1]. On the other hand, the mechanical properties of healthy and cancerous tissue are distinguishable from an early onset [2]. This project exploits the mechanical properties of the tissue to differentiate healthy and cancerous lesions using a soft sensing balloon that can be added to existing endoscopes.

Project overview

In this project students will develop a soft inflatable device which can sense pressure applied and the resulting deformation of the tissue, to distinguish healthy and cancerous areas. The sensor will consist of an inflatable balloon and an integrated sensing: pressure and a reflectance-based proximity sensor to sense the deformation of the balloon wall. Thus, by sensing the pressure and deformation of the tissue, measures of the mechanical properties can be obtained. After a working prototype has been built a suitable phantom experiment should then be designed to test and validate the device, and to assess the range of tissues that can

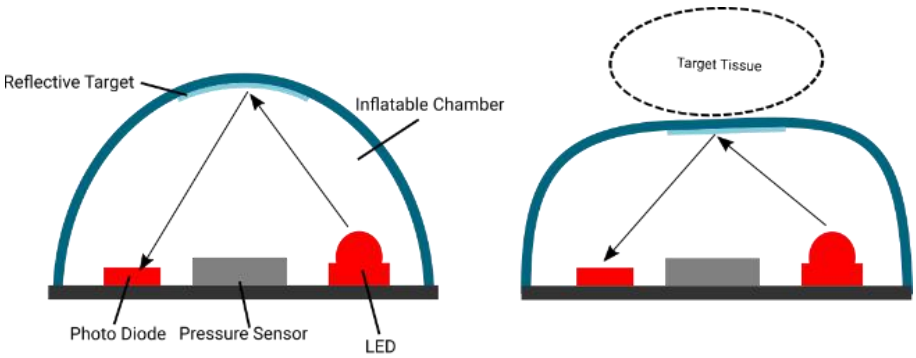


Figure 1 (Left) "Bubble" Sensor concept, changes in pressure and wall deformation sensed by pressure and LED/Photodiode (Right) Contact with tissue changes internal pressure, and distance from rigid base to wall

be detected.

Skeleton project plan

1. Design and fabricate an inflatable sensor using silicone and integrate sensors
2. Design an experiment to test and validate the sensor
3. Validate the sensor's performance in a phantom simulating the colon wall

Hardware/software requirements

- Arduino or similar platform, to interface with the electronics
- Silicone Rubber moulding
- SolidWorks or other CAD software for 3D printing

- MATLAB/C++/Python/other software for data analysis

References

[1] van Rijn J, Reitsma J, Stoker J, Bossuyt P, van Deventer S, Dekker E. Polyp Miss Rate Determined by Tandem Colonoscopy: A Systematic Review. American Journal of Gastroenterology. 2006;101(2):343-50.

[2] Dietrich CF, Barr RG, Farrokh A, Dighe M, Hocke M, Jenssen C, et al. Strain Elastography - How To Do It? Ultrasound Int Open. 2017;3(4):E137-E49.

[3] Avery J, Runciman M, Darzi A, Mylonas G, editors. Shape Sensing of Variable Stiffness Soft Robots using Electrical Impedance Tomography. IEEE International Conference on Robotics and Automation (ICRA); 2019: IEEE.

Project 11: Development of wearable smart sensing platform for non-invasive health monitoring and diagnosis devices

Dr Salzitsa Anastasova, Dr Bruno Rosa, Dr Benny Lo

Aims and Objectives

The aim of this project will be to design and develop a wearable sensor for non-invasive monitoring of vital biomolecules important for wound healing. Both lactate and oxygen are critical biomarkers to access wound healing progression. Inflammation or infectious wound could produce high level of hydrogen peroxide (H_2O_2), which may prevent wound healing process.

Background

Sweat detection is a method of both clinical diagnosis and health monitoring. Online health care services become the development tendency for the future of health care industry. Sweat is a body fluid that can be used as a clinical sample. It gives the opportunity for non-invasive, easy to get and able to realise real-time monitoring. There is a lot of interest in development of wearable sensing platforms for measurement of analytes from skin that can give information about the person's health and wellbeing [1]. Some important parameters are ions (pH, sodium, potassium), glucose, lactic acid, alcohol content. Sweat rate can also be measured and further used as an indicator of temperature imbalances. Physical disorders can change the ingredients of sweat, including producing new components or changing the concentration of the components.

Project overview

The main objective for the proposed project is to advance the platform and further develop the flexible smart patch that enhances real-time electrochemical sensing [2-4].

This will improve the current state-of-the-art in new directions such as integration of continuous sensing in a small non-invasive patch, as well as continuous sampling, crosstalk check, internal validation, and combined sensing.

Skeleton project plan

1. Identification of the working range for the design of the required sensing components
2. A general simulation for the skin predicting dynamic profiles of permeation, distribution, and blood concentration under various modes of transdermal delivery. Analysis of the iontophoresis process
3. Electronics design and investigation of the signal output collection through software for electronics
4. Design, fabrication and testing of multiple sensor embodiments using CAD software and 3D printing
5. Assembly and control of the sensing components and electronics
6. (Possible extension): Development of user interface for sensor control

Hardware/software requirements

- SolidWorks (or other CAD software) and 3D printing
- MATLAB for data analysis and simulations
- MATLAB/LabVIEW/C++/Java/Android studio for user interface development
- CH Instrument for prototype simulation and sensing
- Eagle Cadsoft for electronic device prototyping and assembly

References

1. Tim Dargaville et al., *Biosensors and Bioelectronics*, **2013**, 41, 30–42
2. Salzitsa Anastasova et al., *Biosensors and Bioelectronics*, **2017**, 93, 139-145.

3. Salzitsa Anastasova et al., *Sensors and Actuators B: Chemical*, **2010**, 146, 199-205.
4. Ching-Mei Chen, Salzitsa Anastasova, et al., *IEEE Journal of Biomedical and Health Informatics*, **2019**, 2208 – 2215, **DOI:** 10.1109/JBHI.2019.2957444

Project 12: Assembly, control and characterisation of a fibrebot

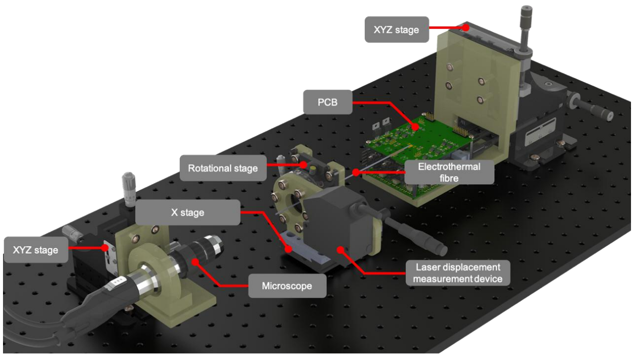
Dr Burak Temelkuran, Mr Jinshi Zhao

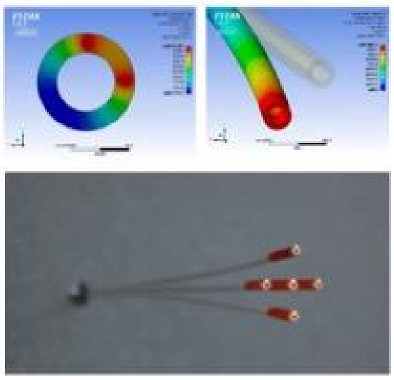
Aims and Objectives

Simulation and experiments will be performed to characterise the motion of an electrothermally actuated [1, 2] fibre robot that will be assembled during this project.

Background

Minimally invasive surgery (MIS) requires small-scale and flexible tools to access challenging surgical sites through natural orifices or tiny incisions. Thus, the steerable miniature soft robots have great prospects in such surgical applications. Additionally, a surgical robot with a flexible miniature body and precise manipulation capacity can improve the feasibility of applying microsurgical techniques in MIS. However, it is challenging for the existing soft robots to have a flexible miniature body and achieve precise motion. Here, we developed a millimetre scale steerable flexible tubular probe that can achieve precise bending motion with 2 degrees of freedom. Miniature therapeutic or diagnostic devices can pass through the central lumen of the probe targeting specific surgical operations. Thermally drawn polymeric fibres embedded with stainless-steel wires are utilised to form the main body of the probe. The low thermal conductivity of the polymers, and the thin wall tubular structure of the probe helps localise the heat generated by the joule heating effect to maintain a high thermal gradient across the small cross-section of the probe. The thermal gradient causes the non-uniform thermal expansion of the material to achieve precise bending motion.





Skeleton project plan

1. Understanding the current system's dynamics and motion limits/capabilities.
2. Simulation of the fibre system using electronics and heat transfer modules in ANSYS.
3. Fibre soldering and integrating to the actuation mechanism.
4. Using LabVIEW and basics of thermodynamics (heat transfer) to control fibre tip.
5. Implement fibre with actuation mechanism and manipulate in real-time.
~~6.~~ Demonstration of fibre robot's precise motion in a phantom.

Key milestones of the project include

- Review state-of-the-art fibre actuation mechanisms.
- Simulate the actuation of the fibre using Finite Element Methods.
- Assemble the fibre robot, control it with software and characterise its motion.
- Conduct a study to recognise and distinguish differences between simulation and experiment.

Hardware/software requirements

SolidWorks, MATLAB

References

1. S. Mirvakili and I. Hunter, "Multidirectional Artificial Muscles from Nylon", Advanced Materials, vol. 29, no. 4, p. 1604734, 2016. Available: 10.1002/adma.201604734.
2. Q. He, Z. Wang, Y. Wang, A. Minori, M. Tolley and S. Cai, "Electrically controlled liquid crystal elastomer–based soft tubular actuator with multimodal actuation", Science Advances, vol. 5, no. 10, p. eaax5746, 2019. Available: 10.1126/sciadv.aax5746.

Project 13: 3D Point Cloud Registration and Fusion from stereo optical video to aid intraoperative gastrointestinal tissue discrimination

Ioannis Gkouzionis, Baoru Huang and Prof. Daniel Elson

Aims and Objectives

The aim of this project is to develop a pipeline to reconstruct a dense three-dimensional (3D) model of tissue surface from stereo optical videos using point cloud registration and fusion methods. The basic idea behind the proposed project is to extract 3D information from video frames and then to mosaic the reconstructed 3D models.

Background

Conventional two-dimensional (2D) imaging systems lack depth perception and do not provide quantitative depth information, thereby limiting the field of vision and operation during surgery. Stereo optical imaging modalities have been widely used in the operating room to provide depth perception to the surgeon. In open and laparoscopic surgery, soft tissue deformations substantially change the surgical site, thus impeding the use of preoperative planning during intraoperative navigation. Extracting depth information from stereo images and building a surface model of the surgical field-of-view is one way to represent this constantly deforming environment. Such information can improve the accuracy of intraoperative navigation [Maier-Hein et al.]. The recovery of 3D tissue structure and morphology could enable the accurate deployment of surgical guidance in minimally invasive surgery. So far, we have used an in-house developed stereo camera system along with a rotating stage and acquired several stereo datasets of tissue phantoms which we would like to construct models, and we have also generated the point clouds for each dataset. This will help us to track optical spectroscopic diagnostic information that has been acquired from these tissue samples.

Skeleton Project Plan

Here, we focus on a procedure that reconstructs the tissue surface from stereo images of a rotating ex-vivo gastrointestinal (GI) specimen. More specifically, it deals with point cloud registration, fusion and finally 3D reconstruction of the tissue model. The chosen algorithm has to be robust, fast and sufficiently accurate. The 3D points should be meshed to create a surface model.

Key milestones of the project include

- 3D reconstruction through point cloud meshing: The generated point clouds are going to be registered and finally fused and smoothed to create the 3D reconstructed tissue model.

Hardware/Software Requirements

- Python, C++ or other suitable programming language
- Stereo Camera developed in-house

References

[1] L. Maier-Hein, P. Mountney, A. Bartoli, H. Elhawary, D. Elson, A. Groch, A. Kolb, M. Rodrigues, J. Sorger, S. Speidel, D. Stoyanov, "Optical techniques for 3D surface reconstruction in computer-assisted laparoscopic surgery", Medical Image Analysis, Volume 17, Issue 8, 2013, Pages 974-996, ISSN 1361-8415, [https://doi.org/10.1016/j.media.2013.04.003].

[2] Lin B, Sun Y, Qian X, Goldgof D, Gitlin R, You Y. “Video-based 3D reconstruction, laparoscope localization and deformation recovery for abdominal minimally invasive surgery: a survey”. Int J Med Robot. 2016;12(2):158-178. [https://doi.org/10.1002/rcs.1661].
[3] Shixun Yan, Sarthak Pathak & Kazunori Umeda (2022) PointpartNet: 3D point-cloud registration via deep part-based feature extraction, Advanced Robotics, 36:15, 724-734, DOI: 10.1080/01691864.2022.2084346. [https://doi.org/10.1080/01691864.2022.2084346].
[4] Leihui Li, Riwei Wang, Xuping Zhang, "A Tutorial Review on Point Cloud Registrations: Principle, Classification, Comparison, and Technology Challenges", Mathematical Problems in Engineering, vol. 2021, Article ID 9953910, 32 pages, 2021. [https://doi.org/10.1155/2021/9953910].

Project 14: Developing a sensing area visualisation tool for laparoscopic drop-in gamma probe

Prof. Daniel Elson, Baoru Huang, and Kaizhong Deng

Aims and objectives

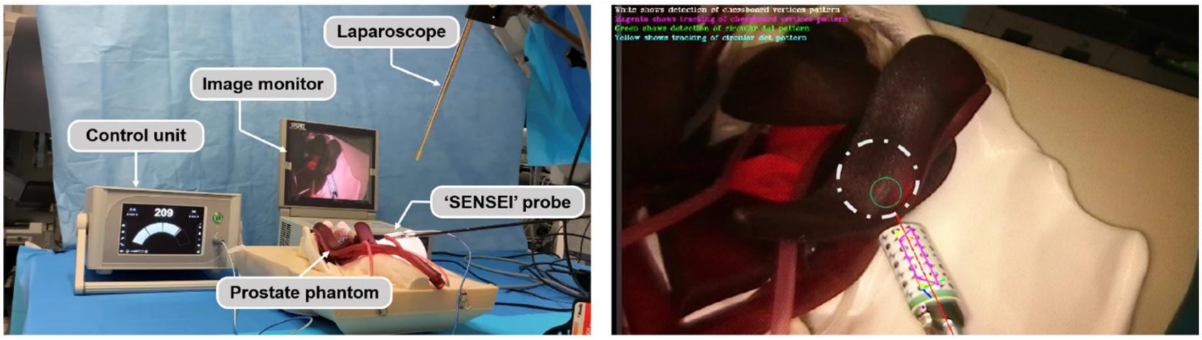
The aim of this project is to develop a sensing area visualisation tool for the laparoscopic drop-in gamma probe.

Background

The drop-in gamma probe is an intraoperative radio-guidance tool designed for robot-assisted laparoscopic surgery [1]. During the surgery, the surgeon will pick up the probe using the forceps and perform the scanning motion in the suspected area. The probe can provide value and acoustic feedback to indicate the hot spot where the radio-isotope accumulated so that the surgeon can navigate to the Sentinel Lymph Node that needs to be resected. It is fully compatible with contemporary surgical techniques and workflows and provides the intraoperative cancer detection function. The tracking of the probe has been implemented in our previous work [2]. In this project, the sensing area will be visualised to enhance the surgeon’s understanding of the sensing area.

Proposed Solution

The visualisation of the probe sensing area depends on the estimated probe pose and the geometry of the target surface. Markers can be attached to the probe so that the tracking algorithm can estimate its pose. The geometry of the surface, represented in the format of a point cloud, can be obtained through a RealSense depth camera. The sensing area can be calculated from the collected probe pose and tissue geometry. After that, it will be visualised in a real-time
image.



Figures: (Left) The hardware setup including a laparoscope, image monitor, prostate phantom, ‘SENSEI’ probe, and control unit; (Right) The laparoscopic image from the detection experiment where the grey circle represents the radioactive source and the green circle shows the sensing area [2]

Skeleton project plan

1. Implement and test the real-time probe tracking algorithm
2. Collect the phantom geometry data
3. Develop a programme to calculate the sensing area
4. Visualise the sensing area in augmented reality

Hardware/software requirements

- Python/MATLAB/C++
- OpenCV
- RealSense

- Gamma probe and phantom model

References

[1] B. Fuerst *et al.*, "First robotic SPECT for minimally invasive sentinel lymph node mapping," *IEEE Transactions on Medical Imaging*, vol. 35, Art. no. 3, 2016, doi: 10.1109/TMI.2015.2498125.

[2] B. Huang *et al.*, "Tracking and visualization of the sensing area for a tethered laparoscopic gamma probe," *International Journal of Computer Assisted Radiology and Surgery*, vol. 15, Art. no. 8, 2020.

Project 15: Eye-controlled Flexible Endoscopy

Dr Adrian Rubio-Solis, Dr Mark Runciman, Jianlin Yang and Dr George Mylonas

Aims and Objectives

The goal of this project is to design and integrate aspects of a gaze-controlled, robotic flexible endoscope.

Background

The endoscope is at the forefront of endoluminal and transluminal surgery. However, as therapeutic endoscopy develops and an increasing number of endoluminal surgical techniques are performed, the endoscope requires modification. Alterations are needed to overcome limitations with the current design and make endoluminal or transluminal procedures a more realistic possibility.

Clinical considerations: Although the endoscope is well suited to the gastrointestinal tract, there are significant challenges with navigating natural bends of the colon for example. Endoscopic maneuvers to navigate past these points can cause discomfort to the patient. Procedures which cause patient pain are more likely to result in a failed procedure, a bad clinical experience and reduce wider uptake of the procedure.

Engineering considerations: Improvements in the endoscope to reduce patient discomfort and operator burden are important. Eye control is an exciting concept which has wide applications including Endoscopy. It is a quick and effective method of control and has already been applied to endoscopy within the department [1,2]. However, the prototype developed requires improvements and modifications to be practical and safe for use in clinical settings.

Skeleton project plan

The project will proceed largely as follows, bearing in mind that several of the tasks can be completed in parallel:

- Investigate components for motorisation of a flexible endoscope (motors, microcontroller, etc.)
- Design and 3D print of endoscope motorisation attachment (motor housing, ergonomic endoscope handle)
- Interface motorised flexible endoscope to eye-tracking glasses for gaze-control.
- Actively sense endoscope steering dials limits (based on sensors or torque)
- Record and playback examination with gaze superimposed on the video.
- Optional: Make a 3D reconstructed visual attention map (could involve SLAM, aurora tracker, markers on the surface of the phantom etc.)

Hardware/software requirements:

- 3D CAD

- Python / C++
- Eye-tracking glasses
- Flexible Endoscope
- Magnetic tracker

References

1. Vrielink, T. O., Puyal, J. G. B., Kogkas, A., Darzi, A., & Mylonas, G. (2018). Intuitive Gaze-Control of a Robotized Flexible Endoscope. In: 2018 IEEE/RSJ IROS.
2. Sivananthan, A., Kogkas, A., Glover, B. et al. (2021). A novel gaze-controlled flexible robotized endoscope; preliminary trial and report. Surg Endosc 35, 4890–4899 (2021). https://doi.org/10.1007/s00464-021-08556-1

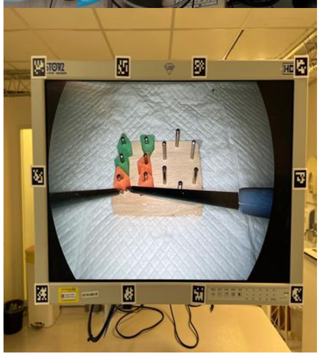
Project 16: Phase Recognition in Laparoscopic Surgery using Deep Learning

Kaizhe Jin, Ravi Naik, Dr Adrian Rubio-Solis and Dr George Mylonas

Aims and objectives

This project aims to develop and implement a Deep Learning approach to recognise phases in laparoscopic surgery. Laparoscopic video and hand movement data will be collected using a capture card and two 9DoF IMU sensors.

Background



Minimally Invasive Surgery (MIS) is associated with less pain, a shorter hospital stay and fewer complications. With recent advancements in minimally invasive surgery and sensing units, rich information including surgical videos and sensor signals can be recorded, providing complementary knowledge for understanding surgical phases. Automated understanding of such complex surgical procedures is highly desired for facilitating cognitive assistance. Surgical phase recognition is fundamentally required for supporting higher-level perception such as surgical decision making, skills assessment and task automation toward the next generation of operating theatres. In robotic surgery, a multimodal deep learning approach was proposed to exploit the informative correlations inherent in visual and kinematics data to boost gesture recognition accuracies [1]. Graph Convolutional Neural Networks (GCN) have demonstrated their ability to deal with complex relationships in multimodal data, including images and time-series data. In robotic surgery, kinematics information can be identified easily through the system, as opposed to conventional laparoscopes. In this case, hand movement in laparoscopic surgery can be the alternative to kinematics information in robotic surgery. Two 9DoF wireless IMU sensors from Shimmer will be utilised to record hand movements. A strategy of combining GCN and Long Short Term Memory (LSTM) can leverage information from hand movement (temporal) and laparoscopic video (visual), potentially improving surgical phase recognition in laparoscopic surgery. To be more specific, in the laparoscopic peg-transfer task, five phases can be recognised, including Idle, reach for the peg, lift peg, exchange peg, and place peg.

Skeleton project plan

1. Design a laparoscopic task, e.g., peg-transfer, with wireless wearable sensors, including two IMU sensors and an Electromyogram (EMG).

2. Acquisition of laparoscopic video and sensor data simultaneously over the Labstreaminglayer (LSL) platform.
3. Data curation and processing, incl. sensor signal filtering and cropping area of interest from the image
4. Synchronise and annotate collected videos and sensor signals.
5. Implement the Deep Learning Networks (e.g., Relational Graph Convolutional Learning)

Hardware/software requirements

- Python, OpenCV
- Linux
- lab streaming layer (LSL)
- Deep learning (Neural Networks)

References

[1] Long, Y., Wu, J.Y., Lu, B., Jin, Y., Unberath, M., Liu, Y.H., Heng, P.A. and Dou, Q., 2021, May. Relational graph learning on visual and kinematics embeddings for accurate gesture recognition in robotic surgery. In *2021 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 13346-13353). IEEE.

Project 17: A Cable Driven Parallel Robot for Minimally Invasive Surgery

Jianlin Yang, Dr Mark Runciman, Dr George Mylonas

Aims and objectives

In this project, a cable-driven parallel robot for Minimally Invasive Surgery will be designed and it is expected to have larger workspace and better dexterity than the last versions [1-3]. A control system will be built to make robot complete some tasks.

Background

Cable-driven parallel robots have been attracting the attention of researchers since their birth. They are used in many occasions, such as cranes, stadium cameras and many other industrial applications. Because of their small size, light weight, high force output and high positioning accuracy, they have demonstrated many advantages and achieved good results since they were first introduced into the field of medical robotics [1-3]. Cable-driven parallel robots have great application prospects in Laparoscopic Surgery, Natural Orifice Transluminal Endoscopic Surgery (NOTES), Neurosurgery, Transoral Laser Phonosurgery and many other medical scenarios. The main objective of this project is to design, build and experimentally evaluate a cable-driven parallel robot with a uniquely different configuration from past versions (Figure 1a). A possible robot configuration for this project is shown in Figure 1b. A cable-supporting scaffold should be designed and fabricated to match the robot configuration. Meanwhile, a master-slave control system is necessary to enable the robot to complete some tasks such as peg-transfer, trajectory tracking and some in vitro experiments.

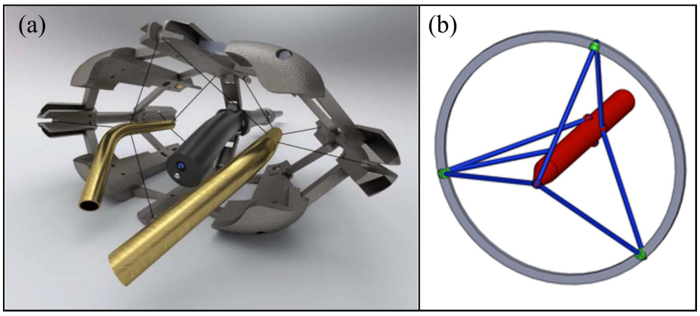


Figure 1: (a) One of the past robot versions (b) A possible robot configuration.

Skeleton project plan

The project will proceed largely as follows, bearing in mind that several of the tasks can be completed in parallel:

1. Design and fabricate a cable-driven parallel robot prototype
2. Develop a master-slave control system for the robot (mechanical, hydraulic, or electromechanical)
3. Build a test platform and validate the robot's performance
4. Possible extension: perform in vitro tasks, such as *Endoscopic Submucosal Dissection (ESD)*.

Hardware/software requirements

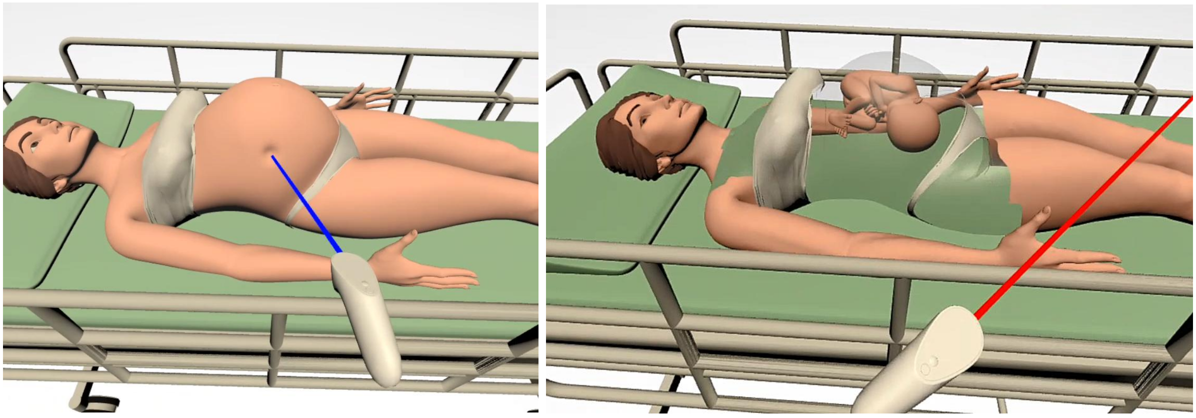
- 3D printer, Omni Phantom device and OPTiTrack tracker
- SolidWorks or other CAD software for robot design (mid-level)
- MATLAB or other similar system for robot simulation and analysis (mid-level)
- MATLAB/C++/Python/other software for robot control (entry-level and depends on implemetation)

References

[1] G. P. Mylonas, V. Vitiello, T. P. Cundy, A. Darzi and G. -Z. Yang, "CYCLOPS: A versatile robotic tool for bimanual single-access and natural-orifice endoscopic surgery," 2014 IEEE International Conference on Robotics and Automation (ICRA), 2014, pp. 2436-2442.
[2] M. Zhao, T. J. C. O. Vrielink, A. A. Kogkas, M. S. Runciman, D. S. Elson and G. P. Mylonas, "LaryngoTORS: A Novel Cable-Driven Parallel Robotic System for Transoral Laser Phonosurgery," in IEEE Robotics and Automation Letters, vol. 5, no. 2, pp. 1516-1523, April 2020.
[3] T. J. C. O. Vrielink, M. Zhao, A. Darzi and G. P. Mylonas, "ESD CYCLOPS: A New Robotic Surgical System for GI Surgery," 2018 IEEE International Conference on Robotics and Automation (ICRA), 2018, pp. 150-157, doi: 10.1109/ICRA.2018.8462698.

Project 18: Virtual Reality System for Obstetric Training

Dr Benny Lo and Miss Jacqueline Tang (Consultant in obstetrics and gynaecology, York Hospital)



Aims and Objectives

The aim of this project is to develop a virtual reality simulation system for obstetric training.

Background

Traditionally, in surgery, there are many educational tools like laparoscopic simulations and 'Desperate Debra' that aids surgeons to be more familiar with procedures and the potential complications. As it is for many practical procedures, trainees are trained through repetitive practices in order to gain confidence and efficiency in operating. However, in the UK, a lot of trainees are trained by practicing and operating on real patients. The benefit of such training is to learn from operating in real-life situation, but that also means that trainees might be operating such procedure for the very first time without being familiar with the steps and approach to it. The other problem is that, with a national shortage of staff, it also means that trainees are struggling to get enough exposure to operate on a regular basis, therefore unable to reinstate what they have learnt from the last procedure. This is where VR simulator becomes useful, not only it will assist trainees to immerse in a real-life environment, feeling the stress and flight in theatre and to get familiar with the steps of operation. It also enhances learning experiences from being able to assess such tools easily and practice surgical steps repetitively. In additional to this, it also allows assessors or trainers to review trainees' progress before hands on experience with patients.
Obstetrics is one of the highest litigation specialties, surgical training has to be robust to ensure safety of mother and baby. Caesarean section rate in the UK is around 25% nationally in the U.K., although it is a common procedure, but it is not without its own risks, including bleeding, damage to bladder or bowels or blood vessels, cut to baby, etc. Currently, there is only the aforementioned Desperate Debra to teach trainees how to deliver a deeply impacted head during a Caesarean section. There are no other simulation modalities to assist trainees in their surgical skills in Caesarean. Introducing modern technology like the VR hopefully will reduce risks of complications to our patients, enhances learning to our trainees to reduce morbidity for mother and baby. There have been papers on the benefits of VR in education for medical students and life support training but very little research on the impact of VR in O&G. The potential of VR in obstetrics and

gynaecology is huge, if this trial is successful, its use can be extended to a wider range of procedures and management of obstetrics emergencies.

Proposed Solution

The group selected for this project should design and implement the simulator on a VR system (i.e. Oculus system), in terms of realistic graphics, simulating tissue deformation, haptic feedback etc. and ideally project should conduct a pilot study on assessing the effectiveness of the simulator for obstetric training.

Skeleton Project Plan

- Familiarise yourselves with the currently implemented simulator in Unity and Oculus Quest
- Review state-of-the-art technology for VR simulator for surgical training
- Investigate methods for generating realistic graphics for simulating an obstetric operation
- Develop methods to simulate tissue deformation and dissections, etc.
- Implement the real-time haptic feedback
- Validate that the implemented simulator with feedback is able to simulate the operation;
- Conduct a study with the clinical staffs in York to assess the usability and performance of the simulator for training

Hardware/software requirements:

- Hardware: Oculus Quest or Oculus Rift.
- Software: Unity and Oculus SDK
- Programming skills: C# (Unity), Python, Oculus SDK

Project 19: Sensing and Control of Soft Robotic Actuators

Dr Mark Runciman, Dr James Avery, Ms Elena Monfort Sanchez, Dr George Mylonas, Dr Alex Thompson

Project Aims

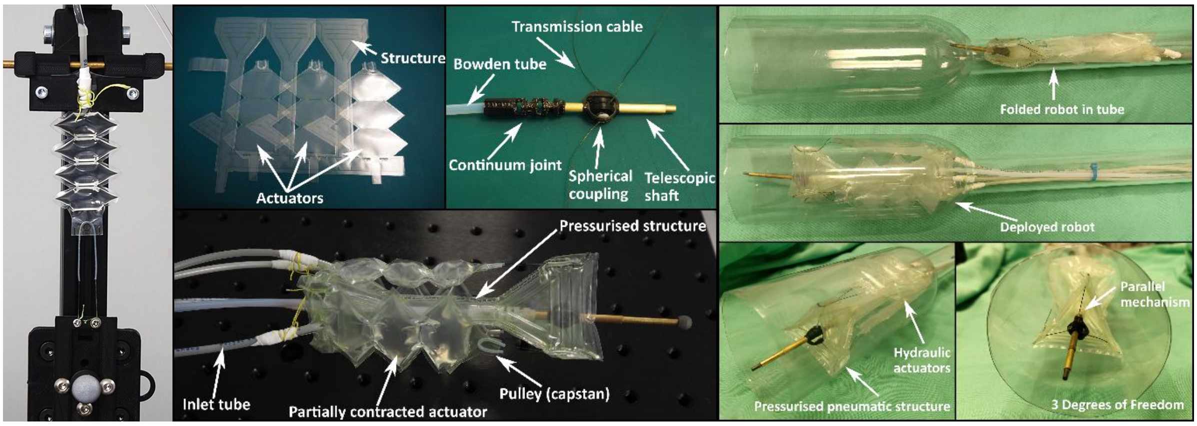
This project aims to integrate a variety of sensors into our novel soft actuators to enable accurate positioning and control in soft robotic devices for minimally invasive surgery.

Background

Soft robots have many potential benefits in applications such as minimally invasive surgery (MIS), such as the ability to change shape, stiffness, and volume [1]. We have developed soft actuators that can exert forces and achieve reproducible positioning appropriate for MIS [2] , however, accurate positioning is still difficult. To achieve reliable sub-millimetre accuracy, improved control strategies have been developed [3] but these require position feedback to not only control position but also estimate external forces.

Project overview

This project consists of integrating sensing modalities (optical and electronic) into the soft actuators to provide position feedback. This project will lead towards integration of the sensorised actuators in robotic platforms, to achieve accurate position and force sensing in soft popup robots.



Left: Single hydraulic soft actuator. Middle: Construction of soft robot with inflatable structure. Right: Soft robot made from inflatable structure, using three soft actuators.

Skeleton project plan

1. Manufacture prototype soft actuators with laser cutter
2. Integrate sensors into soft actuators
3. Build syringe pump actuation units
4. Conduct experiments to characterise performance and model actuator movement

Hardware/software requirements

- SolidWorks or other CAD software
- Electronics, signal processing
- Mechanical testing (Force/torque, stiffness, positioning, speed)
- Arduino (C++)/MATLAB/Python/other software for data analysis

References

[1] M. Runciman, A. Darzi, and G. P. Mylonas, “Soft Robotics in Minimally Invasive Surgery,” *Soft Robot*, vol. 6, no. 4, 2019, doi: 10.1089/soro.2018.0136.

[2] M. Runciman, J. Avery, A. Darzi, and G. Mylonas, “Open Loop Position Control of Soft Hydraulic Actuators for Minimally Invasive Surgery,” *Applied Sciences*, vol. 11, no. 16, 2021, doi: 10.3390/app11167391.

[3] E. Franco, “Energy Shaping Control of Hydraulic Soft Continuum Planar Manipulators,” *IEEE Control Syst Lett*, vol. 6, pp. 1748–1753, 2022, doi: 10.1109/LCSYS.2021.3133128.

Project 20: Popup Soft Robotic Arm for Minimally Invasive Surgery

Dr Mark Runciman, Dr James Avery, Dr George Mylonas

Project Aims

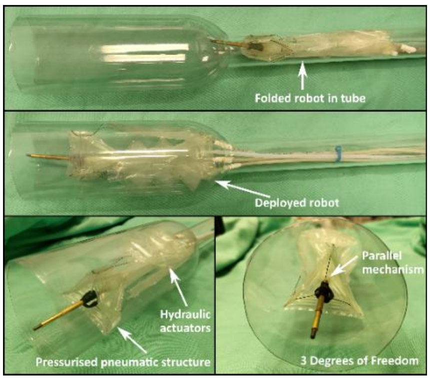
The aim of this project is to create a serial soft robotic arm with both an inflatable structure and inflatable actuators, which will attach to a flexible endoscope. The robot will be able to transition from a state of low volume and stiffness to a rigidified state.

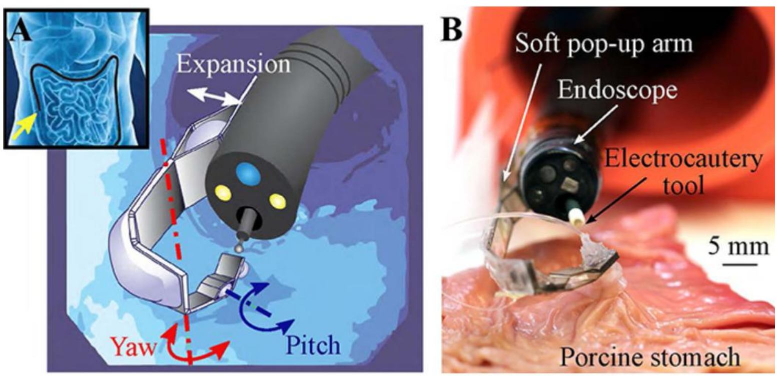
Background

Conventional endoscopes have limited surgical capabilities and could be enhanced with the addition of robotic mechanisms. Advanced surgical techniques such as Endoscopic Submucosal Dissection (ESD) are technically challenging and could be made easier and more accessible with robotic endoscopic surgery. For this purpose, soft robotic devices have many potential benefits such as the ability to change shape, volume, and stiffness [1]. Inflatable devices such as our popup soft robot achieve this, while maintaining a low profile in the inactive state.

Project overview

The project will focus on the design, manufacture, and testing of an inflatable robotic arm to enable accurate positioning of flexible endoscopic instruments. A laser cutter will be used to manufacture fluid actuated components, so the soft robotic components made can be low-cost and disposable. Initial designs will be based on modifying our soft robotic devices to create a serial robot as in [2].





Left: Our popup parallel soft robot; Middle: Diagram of popup robot arm by [2] ; Right: popup arm from [2] used in *ex-vivo* study with flexible endoscope.

Skeleton project plan

1. Design serial robot composed of pneumatic structure and actuators
2. Find welding parameters for manufacture with laser cutter
3. Build actuation unit
4. Conduct experiments to characterise performance

Hardware/software requirements

- SolidWorks or other CAD software
- Mechanical testing (Force/torque, stiffness, positioning, speed)
- Kinematics, control of serial mechanisms
- Arduino(C++)/MATLAB/Python/other software for data analysis

References

[1] M. Runciman, A. Darzi, and G. P. Mylonas, “Soft Robotics in Minimally Invasive Surgery,” *Soft Robot*, vol. 6, no. 4, 2019, doi: 10.1089/soro.2018.0136.

[2] S. Russo, T. Ranzani, C. J. Walsh, and R. J. Wood, “An Additive Millimeter-Scale Fabrication Method for Soft Biocompatible Actuators and Sensors,” *Adv Mater Technol*, vol. 2, no. 10, Oct. 2017, doi: 10.1002/ADMT.201700135.

Project 21: Design and Control of Miniature Soft Actuators for Minimally Invasive Surgical Robots

Jianlin Yang, Dr Mark Runciman, Dr George Mylonas

Aims and objectives

In this project, miniature soft actuators will be fabricated, and a control system and test platform will be built to validate their performance.

Background

Minimally invasive surgery is becoming more and more popular because it brings patients less pain, shorter rehabilitation time, lower complication rates and so on [1]. Surgical robots often need to complete the surgical task in a confined space or a narrow human cavity. Soft robots are a new type of robots, which can adapt to various unstructured environments and interact with the human body safely, and they have several desirable characteristics to make them attractive in minimally invasive surgical procedures. In the past, a family of pouch-like soft actuator have been introduced, which have the advantages of small size and flexible design [2]. The main objective of this project is to design a series of miniature soft actuators based on the original pouch motor. As is shown in Figure (a) and (b), pouch motors are flat and occupy almost no space in deflated state. Figure (c) shows a possible idea for the soft actuator design [3] and it is possible to create many different types of actuators by folding, which can be applied to drive surgical robots. At the same time, a control system is necessary to enable the actuators to move as desired and a test platform is needed to validate their performance.

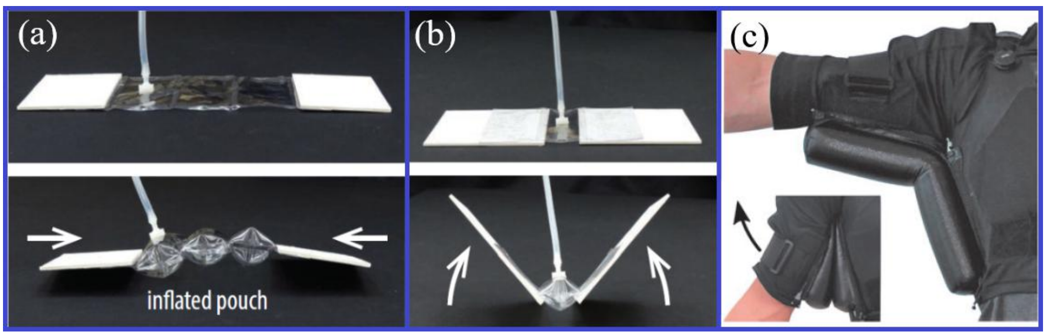


Figure: (a) Linear pouch motors. (b) Rotational pouch motors. (c) Unfolding soft actuators

Skeleton project plan

The project will proceed largely as follows, bearing in mind that several of the tasks can be completed in parallel:

1. Design and fabricate several flat miniature soft actuators
2. Develop a hydraulic control system for the actuators based on Arduino
3. Build a test platform and validate the performance of the actuators
4. Possible extension: use the actuators to drive a cable-driven serial or parallel arm for medical applications.

Hardware/software requirements

- 3D printer, Arduino, laser welding device and OPTiTrack tracker
- SolidWorks or other CAD software for actuator design
- MATLAB or other similar system for simulation and analysis
- MATLAB/C++/Python/other software for actuator control

References

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