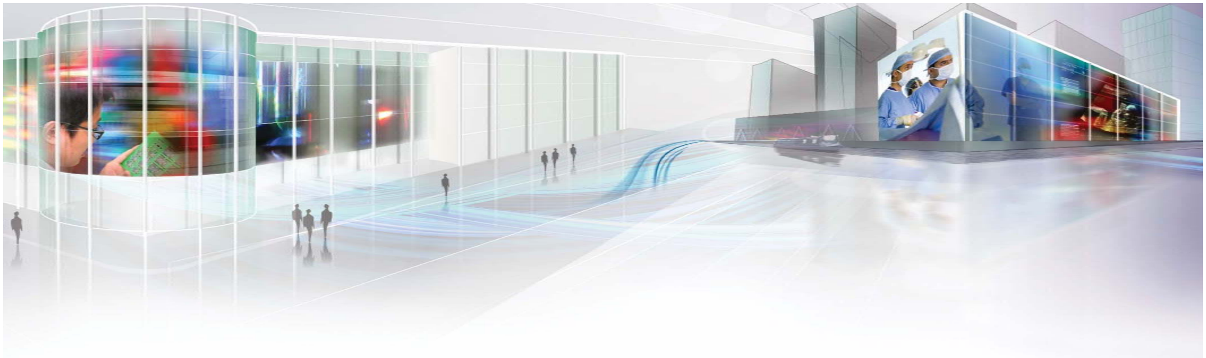

The Hamlyn Centre for Robotic Surgery

- Advancing the integration of robotics in medicine

Founders and Directors: Guang-Zhong Yang and Lord Ara Darzi
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The Hamlyn Centre for Robotic Surgery was established in 2008 with the aim of developing advanced minimally invasive surgical robots that are intelligent, sensor rich and allow seamless human interaction. Establishing this new centre has been made possible through philanthropic support from both the Helen Hamlyn Trust and Lady Hamlyn personally, which initiated a major funding campaign to establish an international centre of excellence for medical robotics in the UK. The Centre, which is based at Imperial College London, is to draw together under one roof world-leading experts in a range of disciplines, with the aim of creating a national and international resource for medical robotics.

Research in surgical robot has an established track record at Imperial College London and the associated activities span across a number of departments of the engineering and medical faculties. From the mechatronics perspective, the team led by Brian Davies, now Emeritus Professor of Medical Robotics at Imperial, began research into medical robotics for neurosurgery, and then a robot for prostatectomy in the mid-80's. This resulted in PROBOT, which in 1991 became the first robot to actively remove tissue from a patient in a clinical setting. In 2001, the team developed a new hands-on robot (ACROBOT) for knee surgery, which introduced the concept of active constraint. This allowed surgeons to cut within safe regions and prevent damage to the surrounding tissue. The routine clinical use of surgical robots for minimal access surgery was initiated in 2001 at Imperial when the surgical team led by Ara Darzi started using the da Vinci surgical robot at St Mary's Hospital of Imperial College Medical School. The system was used extensively for Endoscopic Radical Prostetectomy, Hiatal Hernia Surgery, and Low Pelvic and Rectal Surgery. The first Totally

Endoscopic Robotic Coronary Artery Bypass (TECAB) was carried out at St Mary's Hospital in 2003. During this period, the clinical use of the da Vinci system has also shown significant challenges in dealing with surgical guidance and navigation where there is large soft tissue deformation. The team led by Guang-Zhong Yang tackled a number of techniques for imaging, sensing, 3D depth recovery and 2D/3D registration methods for robotic assisted laparoscopic surgery. This has resulted in a number of innovative approaches including the concept of *perceptual docking* for the development of the next generation surgical robot. The major focus of the Hamlyn Centre for Robotic Surgery is to develop robotic technologies that will transform the conventional minimally invasive surgery and explore new ways of empowering robot with human intelligence and miniature "microbots" with integrated sensing and imaging for targeted therapy and treatment.

Core Research Themes of the Centre

Flexible Telemanipulators

In robotic assisted minimal invasive surgery, the use of miniaturised master-slave instruments has significantly increased the degrees-of-freedom of surgical manipulation but its application to more advanced cardiac procedures, such as multi-vessel bypass, or complex gastrointestinal procedures is limited. Existing designs are generally unsuitable for following curved operation pathways where obstacle avoidance is critical. Flexible, snake-like manipulators have obvious advantages in that they are not restricted to straight-line paths. They can navigate within lumens and confined spaces, and are able to move around obstructions to gain access to restricted areas. An obvious, early application of snake manipulators is the form of an intelligent flexible endoscope which can naturally follow the contours of the digestive tract or of the sulci within the brain or of muscle planes in tissue. This allows an anatomically natural approach, reducing iatrogenic damage. On reaching the desired location, it is possible to use direct endoscopic visualisation to control the manipulator to perform diagnostic and therapeutic functions. One of the key research programmes of the Centre is to develop a flexible robotic system for NOTES (Natural Orifice Transluminal Endoscopic Surgery). This includes navigational and localising functionality integrated with miniaturised and ergonomically designed instruments for tasks such as tissue resection, haemostasis, anastomosis and suturing. Preliminary studies have already been conducted by the Centre for the i-Snake surgical robot (Imaging-Sensing Navigated And Kinematically Enhanced Surgical Robot), which integrates imaging and sensing with kinematically enhanced instrument design to facilitate intra-luminal or extra-luminal curved anatomical pathway navigation, thus enabling an expansion of applications for robotic assisted minimally invasive surgery to perform intra-organ (*i.e.* cardiac), intra-luminal therapy (vascular and gastrointestinal) and intra-cavity procedures. For cardiac applications, the systems to be developed at the Centre will enhance robot-assisted stenting, difibrillation and valve repair, incorporating motion compensation techniques and intelligent sensor-based monitoring of performance and haptic feedback.

Perceptual Docking and Active Constraints

Although the fine manipulation capabilities of the current robotic systems in performing scaled down, steady, tremor-free motion are well appreciated, the future clinical impact of the technology will rely on the machine intelligence of the system and its ability in bridging the sensory information such as vision and tactile feedback between the tool tip and human hands. One of the significant focuses of the Centre is to develop and promote the perceptual docking concept for the development of next generation surgical robot. The word docking is different in meaning to the conventional term used in mobile robots. It represents a fundamental paradigm shift of perceptual learning and knowledge acquisition for robotic systems in that operator specific motor and perceptual or cognitive behaviour is assimilated *in situ* through different sensing channels. For example, for motion compensation or stabilisation in complex procedures, whilst the use of conventional computer vision techniques for 3D structural recovery and registration for intra-operative guidance has encountered major difficulties in the presence of large tissue deformation, there has been very limited work in making effective use of the human vision system for simplifying, as well as augmenting, some of the complex visual processing tasks. Humans have unexcelled flexibility and hand-eye coordination, as well as finely developed sense of touch. Our vision system is particularly superior in image understanding, feature tracking, 3D perception, morphological registration, and integrating diverse sources of visual cues. We have already demonstrated that saccadic eye movements and ocular vergence can be used for attention selection and recovering 3D motion and deformation of the soft tissue during minimally invasive surgical procedures. It is expected that the method will also open up a range of new opportunities for effective human-machine interaction.

For example, executing dexterous surgical tasks under a static frame of reference for moving object is one of the ultimate goals of robotic surgery. Current approaches to motion stabilisation are mainly achieved through a mechanical endoscopic stabilizer which provides intracorporeal articulation and facilitates placement of the device to the target vessel. To avoid inadvertent tissue damage, the concept of active constraints (or virtual fixtures, surgical macros) has been introduced. If the tool approaches a volume of space previously defined to be forbidden, the robot prevents further motion in that direction. The synergistic system allows the surgeon's skills and judgment to be combined with the precise constraints provided by the robot, allowing an accurate and safe operation. In implementations of active constraints to date, the boundaries have always been defined pre-operatively and have remained static throughout the operation. To perform dynamic update of the constraints in response to tissue deformation and changing surgical conditions, significant hurdles need to be overcome for the accurate extraction of 3D structural changes either through intra-operative imaging or biomechanical modelling of the target anatomy. The optimum combination for soft tissue surgery is likely to be a dual guidance robot with the capability for image guided surgery and telemanipulation, and by integrating human perception/cognition with machine manipulation, *i.e.*, through the use of perceptual docking.

Movement compensation involves synchronisation with moving structures to enable dynamic matching of motion between the robot and the tracked organ through predictive modelling. Mechatronically, the Centre's research programme will focus on low inertia mechanics that offer the high frequency tracking capability necessary for a dynamic response. Research is also underway to improve the *dependability* of advanced robots, which embraces safety, reliability, maintainability, availability and "legibility" – the psychological ability of a user to understand what the robot is intending. The safety of advanced robots especially in the case of redundant kinematics and/or a measure of robot autonomy in path planning and collision avoidance has been identified as an area requiring special attention. It is expected that the *perceptual docking* concept will facilitate improved motion stabilisation, intra-operative guidance, and active constraints, thus improving the overall operating accuracy and consistency of the robotic systems.

Autonomous Microrobots

This is a relatively long-term research focus of the Centre and embraces a wide swathe of enabling technologies including mobility, actuation, navigation, non-image sensing, software architectures and multiple robot co-operation. The one generally available micro robotic device currently is the swallowable camera. This has only an imaging function, but a logical next step is to equip a swallowable device with actuation, enabling it to anchor itself against peristaltic flow in order to carry out a surgical function such as biopsy or polypectomy. More far reaching applications of micro and nano scale devices have been proposed and are being researched. To date, much of the basic enabling technologies are still at an early stage, however, the range of therapies suitable for precision targeting to sites within the body using minimally invasive access is increasing. Robots are well placed to deliver these new treatment. One important research issue is related to fault tolerance and recovery. Non-medical examples of autonomous robots operating in hazardous environments have included various hardware and control strategies for coping with performance degradation and failure, and many of the existing concepts could be adapted to micro scale intra-corporeal robots. The development of strategies for controlling swarms of micro robots is highly relevant in the longer term, leading potentially to the development of "robotic phagocytes" able to navigate to infected or damaged areas and deliver treatment, or of robotic systems carrying radiation for high intensity temporary brachytherapy.

Collaboration and Outreach

Whilst pursuing its own research agenda, the Centre is expected to play an active role in international collaboration and outreach activities, as well as training of surgeons and engineers in robotic technology to facilitate its integration with medicine. Medical robotics and computer assisted surgery are used in a growing number of operating rooms around the world. The need to perform delicate surgical procedures safely in tight spaces where the surgeon cannot see directly has created a growing demand for devices that act as extensions of the surgeon's eyes and hands. This creates a unique opportunity of developing new robotic devices that build on the latest developments in imaging, sensing, mechatronics, and machine vision. The creation of this centre allows the research team to leverage our existing research programmes in pursuing adventurous, fundamentally new technologies that will allow more wide-spread use of robotics in medicine and patient care.