An overview of medical robotics in Iran

This paper presents an overview of the current research and development activities on medical robotics in the Islamic Republic of Iran. Medical robotics is believed to be among the most influential and therefore strategic technologies in the area of health and medical services. As a result, the Iranian Ministry of Education, along with the Ministry of Health and Medical education and the Ministry of Industries and Mines have devised a strategic plan to promote and support this branch of technology. A research centre (called RcSTIM) has been assigned to focus on this area and work intensively on long term projects. Collaborative research and development projects in this centre and other technical and/or medical schools have resulted in several domestic technologies and advancements in the field of medical robotics, from which some have already entered the last stages of commercialization and others are passing technical and clinical trials.

By Farzam FARAHMAND (*) (**), Hamid R. AMIRNIA***, Saeed SARKAR**, Saeed BEHZADIPOUR**, Alireza AHMADIAN** and Alireza MIRBAGHERI (*) (**) (****)

MEDICAL ROBOTICS: AN EMERGING DISCIPLINE

Computer assisted and robotic surgery procedures are becoming common clinical practices in recent years as a result of the rising tendency towards minimally invasive and geometrically precise surgeries. They are proved to provide better clinical results and lower the overall costs through shorter hospital stays, shorter recovery times, and reduced need for repeated surgeries. The domain of its applications has now been extended to the full spectrum of medical treatment, from diagnosis to preoperative planning, surgery execution, and postoperative rehabilitation. The products are thus rather diverse, ranging from modelling and visualization software tools to surgical simulator units, navigation systems, surgical robots, and robotic rehabilitation apparatuses. The discipline inherently involves the integration of many different computer-related technologies. Modern medical imaging systems, such as CT, MR, PET, together with

---

* RcSTIM, Tehran University of Medical Sciences, Tehran, Iran.

** School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran.

*** Center for Innovation and Technology Cooperation, I.R Iran Presidency, Tehran, Iran.

**** http://www.wisegeek.com/what-is-physical-therapy.htm advanced techniques of image processing and modelling, 3D anatomy visualization, real-time tracking and sensing, haptics and robotics are considered to be the key underlying technologies in this field.

Considering the wide range of technologies, products and applications, different names have been assigned to the discipline, e.g., image-guided surgery, computer-assisted surgery, medical robotics, medical virtual reality, and computer-integrated surgery. We prefer the term "medical robotics", as it emphasizes the underlying technologies more comprehensively and includes all the tools developed for a range of applications as wide as the medical science itself. It should be noted that the term robotics in this context does not necessarily refer to a robotic mechanism, but indicates an application of the multidisciplinary and the vast robotic science in medicine. The science spans a wide spectrum of fields and techniques such as image processing, 3D object modelling, computer aided design, coordinate measurement and navigation, motion planning, man-machine-interfacing, control and finally design and analysis of mechanisms. Each of the above-mentioned branches of this science has found exciting applications in the medical sciences and is referred to as medical robotics.

MEDICAL ROBOTICS RESEARCH IN IRAN

The research and clinical activity to develop new products and clinical applications for computer assisted and medical robotic systems are increasing sharply worldwide. Following a detailed study on the emerging medical technologies sponsored by the Ministry of Industries and Mines of the I.R. Iran [1] the significant and critical role of this discipline in the prospect of the medicine was formally identified. Consequently, a research lab was established at the Research Centre for Science and Technology In Medicine (RcSTIM) in 2003 for long term concentrated work in this field. A strategy was designated to the lab, focusing on three main points as summarized below:

Active and close collaboration with clinicians - This is essential for an engineering research laboratory such as ours, if a significant contribution to this emerging field was aimed. Close and active collaboration with clinicians makes it possible to identify and understand the real problem in a particular application and to find out if a potential solution works in a clinical environment. On the other hand, progress towards an effective solution is often best developed in the context of a team work with specialists from different disciplines.

Establishment of appropriate infrastructures - A significant contribution to this emerging field requires continuous long-term efforts which are conceivable through establishing the appropriate human, software, hardware and financial infrastructures. This includes attracting and educating the interested engineering and medical graduate students, developing the software tools which are fundamental to a large variety of applications, e.g., image-based modelling of anatomy, preparing conventional sensors, motors, mechanical components and robotic modules and finally making long term agreements with the interested investment parties.

Applied research towards commercialize-able products - The research should aim problems that are clinically important, seem solvable, require innovation, and could be addressed in due time. This often necessitates developing integrated solutions combining appropriate technologies such as image processing, modelling and analysis, real-time sensing, and manipulation aids to solve a particular problem. The solution should make a significant difference in treatment outcomes and cost-effectiveness. The solution should be pursued at different levels, starting with rapid and iterative generation of prototypes with end-user evaluations to develop more complete solutions. The resulting products and technologies should be applicable in common clinical practices at different development levels; the first versions are to be commercialized in near future while more complete in depth solutions will be explored in the long term. The resulting products and technologies are to be transferred into other groups and enterprises with the required skills of manufacturing, marketing, and supporting for the commercialization.

In implementing this strategy, RcSTIM has worked on a variety of research projects in partnership with clinicians at several hospitals such as Imam Khomeyni Hospital, a leading medical centre in Tehran. A wide range of clinical problems were identified and appropriate technologies were pursued, mainly in four key areas including geometric modelling and registration, virtual reality in medicine, surgical robots, and robotic rehabilitation systems. The projects were supported in preliminary stages of concept development by the Tehran University of Medical Sciences and Sharif University of Technology, and in the technology development stage by the Small Business Development Centre (SBDC) of Industrial Development and Renovation Organization (IDRO) of the I.R. Iran.

While RcSTIM has taken the main role of leadership in the development of domestic medical robotics, technical universities and research centres in the country have also contributed to this field through various research projects some of which have been conducted in collaboration with medical centres. This article tries to elaborate the most successful projects pursued by these institutions.

Surface Modelling

The development of powerful medical imaging systems and the need for 3D geometrical models for surgical applications have brought a new perspective into the anatomical modelling in recent years. Modern medical imaging systems, e.g., Magnetic Resonance Imaging (MRI) and CT scanning, provide detailed cross sectional images of the human tissues which can be processed through segmentation algorithms to extract the 3-D data of an individual tissue. However, the resulting discrete data needs to be further processed through continuous mathematical representation to produce 3-D visualizations for computer preplanning and/or simulation of surgical procedures. Moreover, there is a high potential for application of analytical representations in the areas of diagnosis, monitoring of disease progress or assessment of surgical outcome. On the other hand, many computer-assisted and robotic surgery applications, e.g., surgical navigation systems, require 3-D geometrical models to be registered to the anatomy or to other images.

Mathematical representation of complicated three dimensional surfaces has been a major concern for biomedical engineers in recent years. This includes two steps which are usually performed simultaneously by mathematical techniques, i.e., data smoothing and surface modelling. The smoothing process is essential since the experimental data generally contains a degree of error, leading to creation of ripples in the model, if the mathematical representation of the surface passes exactly through every experimental data point. Data smoothing is achieved using approximation methods, namely the least-square technique, and reduces or eliminates the effect of ripples. The surface modelling is generally conducted using mathematical equations of basic (e.g., polynomials) or piecewise (e.g., B-spline) form for representation of simplified or complicated surfaces, respectively [2].

A modelling method which can be used as a general tool for bio-surface applications needs special capabilities. Bio-surfaces are usually much more complicated than regular engineering surfaces; a flat part may swiftly slope to a needle shape knob or a convex zone can suddenly jog into a concave region. This limits the application of newly developed Computer-aided design (CAD) techniques [3] in bio-surface field. On the other hand, a general tool for modelling bio- surfaces requires providing adequate accuracy in representing the real anatomy. The degree of accuracy required, of course, is variable depending on the nature of each specific application. However, in most medical applications, an accuracy in the order of ±0.5 mm is sufficient [2].

The B-spline method has both of the above requirements to stand as a general tool for modelling the bio-surfaces. However, despite its versatility in representation of complicated bio-surfaces, the classic B-spline least-square method has some limitations. First of all, it requires a complete rectangular net of data points which is not usually available for bio-surfaces and needs to be produced via extrapolation [2]. Moreover, the smoothing intensity of B-spline method depends on the number of the control points; hence not only it is a discrete parameter and cannot be changed continuously, a higher smoothing degree requires using a lower number of control points, losing some details of the surface. Finally, the least square formulation of B-spline surfaces is somehow complicated, especially in the common case of moment free edges which leads to constrained Lagrangian optimization.

Considering the limitations of B-spline least-square method, a research group at the RcSTIM has developed a novel, general-purpose algorithm with broad applicability, both within the context of surgery applications and biomechanical investigations [4, 5]. This algorithm is based on the analogy between the B-spline curve modelling and the force-deflection behaviour of a beam subjected to lateral point loads. Mathematical formulations were developed to extend the algorithm so that it can be used for mathematical modelling of incomplete nets of data points, as well as smoothing of noisy and/or filtering of erroneous data points. The required unknown parameters could be solved explicitly, with no need to solve the system of equations simultaneously. The performance of the proposed technique was evaluated on a number of surface modelling problems, including two known analytical surfaces of the human femoral and patellar articular surfaces (Fig. 1). The results indicated that the proposed method was precise, flexible and easy to apply, and has several advantages over the conventional smoothing method, i.e., the B-spline approach. However, further work is being conducted to develop a new method with more capabilities based on the influence surface modelling approach and least square method.

Surface Registration

Registration is the process of finding a mapping between anatomical or functional information in two different spaces, i.e., coordinate systems, so that data that correspond to the same anatomical position are mapped to each other [6]. Registration of medical imaging and/or functional information acquired using different modalities, e.g., x-ray, CT, MR, PET, SPECT, from different viewpoints, or at different times makes it possible to combine different types of

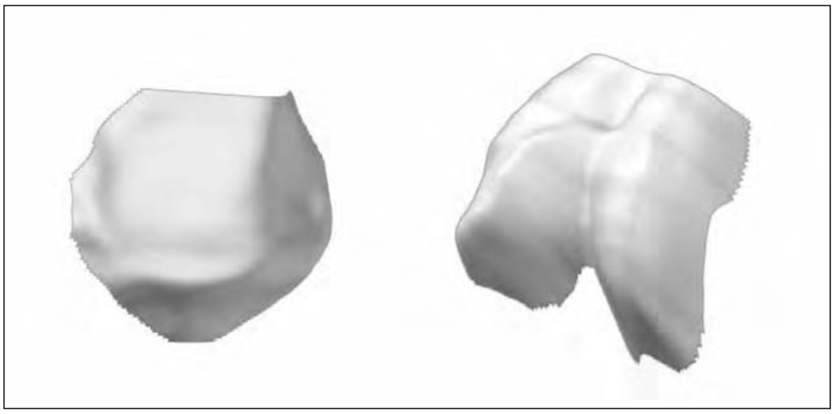

Figure 1: The 3-D representation of the patella (left) and femur (right) of the CT data developed by the proposed technique.

structural information for diagnosis and surgical planning, as well as monitoring the disease progression/regression and postoperative follow ups. More important, however, is the registration of preoperative medical images or model with the patient's body during surgery, which is considered to be a fundamental requirement for interactive intra-operative navigational guidance in computer assisted and robotic surgeries. In surgical navigation systems the image-to-physical registration transformation is used to track and direct a surgical tool on a display of the preoperative images towards an anatomical target, e.g. a tumor.

Many registration methods have been proposed and used for clinical applications. A registration technique for general use in surgical navigation systems should be effective, fast, and simple to apply. The simple method of using anatomic landmarks is not an effective method since these are often difficult to find and sometimes do not exist. Registration using stereotactic frame systems has been used since the early 1970's in image-guided stereotactic surgery. Such systems, however, had several limitations; the frames were bulky and were likely to interfere with the surgical exposures, patients complained about the weight of frames and the pain due to their application, the surgeon was typically limited to target points on a linear trajectory, and most importantly, frame-based stereotactic systems did not provide real-time feedback to the surgeon about anatomical structures encountered in the surgical field.

To address these limitations, a number of frameless navigation systems have been developed over the last decade. The most commonly used method is the iterative-closest-point (ICP) algorithm developed by Besl and McKay (1992) for registration of a 3D set of points to a 3D model that minimizes the sum of squared residual errors between the set and the model [7]. More advanced surface-based and volume-based methods have been proposed recently and have been demonstrated to be more effective and accurate; however, they all need a large number of data points to be measured before starting the surgery.

Considering this important limitation, a project was pursued at the RcSTIM that proposed a new technique for surface registration, based on the transformation relationships between the initial and transferred state of a mathematical function in space [8]. This was then extended to any points cloud using a mathematical representation for complicated freeform surfaces using the influence surface modelling approach and least square method [9]. The performance of the system has been evaluated for registration of some analytical surfaces as well as the articular surfaces of human knee in two MRI senses to obtain the joints kinematical data. In general, the proposed method was found to be a powerful and accurate technique for registration of complicated freeform surfaces with high accuracies of ±1 mm and ±1 degree and fewer data points. However, further investigation is needed to compare the performance of this technique with the methods currently in use, from both the accuracy and computational efficiency points of view.

Surgical Navigation System

Traditionally, surgeons have had to rely on two dimensional X-rays coupled with their knowledge of human anatomy to prepare for surgical procedures. Once patients were opened up, surgeons relying on the traditional methods were only able to see the part of the anatomy that was exposed. This leaves patients with tumors deeply embedded in healthy tissues very vulnerable.

The state of the art image-guided surgical navigation allows surgeons to look inside the body to detect the infected tissues inside cavities, narrow passageways inside arteries and awkwardly positioned tumors deep inside the brain by sophisticated navigation through organs using three-dimensional (3D) images as their guide. Because the view is so precise and controllable, the surgeon can actually see where the healthy tissue ends and a brain tumor begins, or precisely helps him to decide where on the spine to place a pedicle screw to maximize patient mobility. This system enables surgeons to create an exact, detailed plan for the surgery. The technology leads to shortening the operating times, decreasing the size of the patient's incision, and reducing the procedure's invasiveness, all of which can lead to better patient outcomes and faster recovery.

A project has been started since 2005 at the RcSTIM to develop an image-guided surgery and navigation system, and the first prototype was released in 2011 [10]. The system includes an optical camera to track the surgery tools as well as the software tools to build a 3D model of the patient anatomy prior to the operation and registration techniques (see Fig. 2).

During surgery the instrument communicates with the computer and surgeon in real time basis. This means the surgeon can watch on a computer monitor as one precisely operates on the sensible organ. Looking at the computer monitor, the surgeon can see the position of the instrument as it relates to portions of the patient's anatomy that are beneath the surface of skin, hidden from the surgeon's direct view. Therefore, because of the provided virtual anatomy model of the patient, the surgeon does not need to make a large incision just to expose and see the anatomy underneath the skin.

As explained earlier, the success of an image-guided surgery system depends mostly mainly on the algorithms employed for real-time and accurate coordinate measurement and processing of 3D modelling human anatomy. The development of the image-guided surgery system at the RcSTIM was enabled through several research and development smaller projects to obtain the required tools on 3D surface modelling, model registration and real-time tracking of the objects. Some of these activities are detailed below.

VIRTUAL REALITY IN MEDICINE

A virtual reality system in general includes a 3-D computer simulation and a set of human-interface instruments that allow a user to interact efficiently with the computerized model in real time using his natural senses and skills. Clinically validated, powerful medical virtual reality simulators are now available and in use all over the world, both for surgical training/assessment and for pre-planning/execution of surgical procedures [11]. In particular, they facilitate the training process of laparoscopic surgery trainees who need to be prepared for more complex gestures and hand-eye coordination, considering the loss of direct visual and tactile information during this type of surgery.

Surgical Simulation System

A surgical simulation system incorporates a virtual reality interactive graphical environment [11] and a force feedback device [12]. Among the several key problems in the development of the graphical environment of a surgical simulator, realistic real-time simulation of the mechanical interactions between the virtual objects, i.e., the surgical instrument, and the human organ, remains the most important issue. This involves a collision detection algorithm to check continuously if the instrument collides with the tissue and to identify the collision point, as well as a modelling algorithm to provide a realistic graphical display of the tissue's response to the external mechanical loads applied by the instrument. These algorithms must be at the same time accurate, to mimic reality, and efficient, to be executable in real-time, in an endeavour to create a make-believe simulation.

Several methods have been proposed in the literature for fast computation of mechanical deformations, including the non-physical models, e.g., free-form deformable representations and deformable splines, the discrete models, e.g., mass-spring systems, linked volumes, chain-mail representations, finite sphere and point-associated finite field models, and those

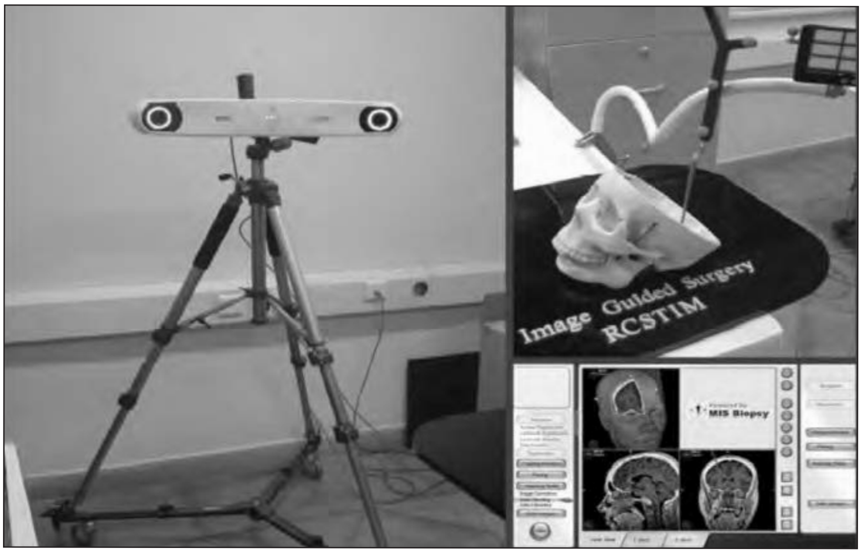

Figure 2: The first prototype of a navigation system for image guided surgery developed at the RcSTIM.

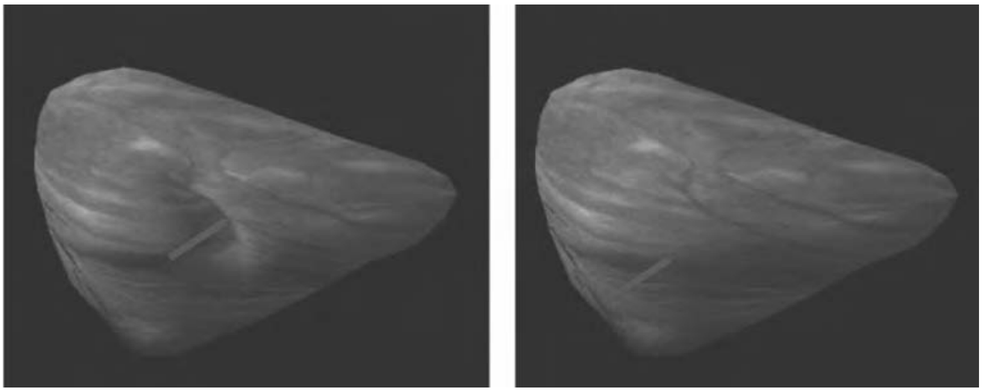

Figure 3: Interactive simulation of a liver model under deformation. The simulation was run at a rate of 200 iterations per second, and the screen was updated every 10 iterations (20Hz visual update).

based on continuum mechanics, e.g., the finite element and the boundary element models. While each of these models has found an advantageous position its own among the diverse applications of deformable modelling, there are concerns over their application in surgical simulation, due to the complicated behaviour of living tissues. In particular, computationally intensive continuum based methods are only capable of simulating small deformations of linear elastic materials in real time. However, as biomechanical literature [13] suggests, the behaviour of living soft tissues is highly nonlinear and time and rate dependent, i.e., viscoelastic, and linear elasticity is only a coarse approximation of their real properties.

Considering the above-mentioned facts, a project has started at the RcSTIM to develop a model for more sophisticated and realistic simulation of the soft tissue deformation during laparoscopic surgery in real time. The project pursued both discrete modelling [11, 14] as well as finite element [15, 16], and meshless continuous approach [17]. The important issues of tuning the model's parameters as well as the collision detection and simulation were also addressed using new practical algorithms to provide a total solution for an interactive graphical environment for a laparoscopic surgical simulator. Results (Fig. 3) indicated that the model can well replicate the complicated mechanical behaviour of biological tissues, e.g., the nonlinear 'toe' region of the force-deformation curve, the strain rate dependent response, and the creeping, relaxation and hysteresis phenomena. The simulated response of the model after tuning in its parameters to the experimental data of a deer liver sample, closely tracked the reference data with very high correlation coefficients and maximum relative differences of less than 5% and 10%, for the tuning and testing data sets, respectively. Finally, the implementation of the proposed model and algorithms in a graphical environment resulted in a visually real-time simulation with updating rates of 150 Hz for interactive deformation and 30 Hz for visual rendering.

SURGICAL ROBOTS

The use of robots and robotic systems in surgical theatres has been rising increasingly in recent years. Surgical robots aim at providing the surgeon with a new set of versatile and effective tools to extend his authority in conducting the operation. They are not supposed to and cannot replace the surgeon, as the surgical procedure is a highly interactive process with many decisions made during the operation. In fact, surgical robots are a special subclass of robots, the master slave manipulators, which work cooperatively with surgeons as surgical assistants.

Currently, there are two main categories of surgical assistant robots. The first category includes surgeon extenders robotic systems that are operated directly by the surgeon to augment or supplement his ability to manipulate surgical instruments [18]. These systems can extend the surgeon's capabilities dramatically, e.g., eliminate his hand tremor or allow dexterous manoeuvres inside the patient's body, to shorten the operation period, reduce the morbidity or error rates, and treat otherwise untreatable conditions. Examples of the robotic systems in this category are telerobotic instruments. These instruments include a slave manipulator, controlled through a spatially consistent and intuitive master with a force feedback (haptic) system and can replace the tactile sensibilities and restore the surgeon's dexterity, diminished during minimal invasive surgery. One such system that is currently in use is the Vinci surgical system including two major components: a console for surgeon's viewing and control, and also two or more surgical arms, which hold and manipulate the detachable surgical instruments [18].

The second category includes auxiliary surgical robots. These systems generally work together with the surgeon and help him in conducting the surgical tasks by performing some auxiliary functions, e.g., holding the endoscope or retracting the neighbouring tissues. Typically one or more human-machine interfaces, e.g., joystick, head tracker, voice control, etc., is used to provide direct control of these systems, however, there has been efforts to make them intelligent so that they can work automatically with less need to the surgeon's direct control [18].

Some considerations should be taken into account during the design and development of surgical robots. Surgical robots must be compatible with the operating theatre and have sufficient strength, accuracy, and dexterity for their intended use. They must be placed or mounted where they could perform their intended duty, e.g., on the floor, or the operating table, or the ceiling, allowing access to the patient's body by surgical staff. Any part of the robot that might come into contact with the patient or which may contaminate the surgical field must be sterilized or covered with a sterile cover. Furthermore, for image guided operations, they should provide translucency, compactness and compatibility with imaging devices, e.g., MRI. Finally, the important feature of safety must be observed in the design, manufacturing, and application of surgical robots, e.g., thorough multiple emergency stop and checkpoint/restart facilities, redundancy in safety-critical systems; avoidance of unnecessary speed or power in actuators, and rigorous design analysis, documentation, and testing protocols.

Auxiliary surgical robotic tools

Laparoscopic surgery is a branch of minimally invasive surgery that is performed in the abdominal cavity. During laparoscopic surgery, endoscopic instruments are passed through small incisions on the abdominal wall, to reach the surgical site within the patient's abdomen. A long stem laparoscopic lens, attached to a special CCD camera, provides insight view on the surgical site and allows the surgeon to explore the intra-abdominal organs and structures. The use of laparoscopic surgery has increased during the past two decades due to the fact that small incisions are often much less traumatic, causing less postoperative pain and earlier return to normal activities. However, these procedures are more difficult to perform and need more skilful surgeons, since the direct eye-hand coordination is lost.

Efforts have been done to facilitate the laparoscopic surgery procedure by employing robotic systems. In particular, the use of robotic systems to assist surgeons by performing routine tasks such as laparoscopic camera manipulation is becoming a common practice. These systems reduce the need to assistive staff and provide more stability with no fatigue and inattention. Furthermore, they provide a larger space for surgeon's manoeuvres and improved direct control with high geometrical accuracy. The motion of the endoscope is controlled by the surgeon using a human–machine interface, e.g., a joystick, foot pedal, voice, or by tracking the surgeon's head movements. Several examples of such laparoscopic robotic cameramen have been introduced in the literature; however, only a few of them [19, 20] have been commercialized.

A project called Robolens was started at the RcSTIM to design and develop a robotic cameraman for laparoscopic surgery, which is dexterous, effective, easy to use, safe and less expensive [21]. The key attribute characteristic of the Robolens system (Fig. 4) is its novel design with the minimum number of degrees of freedom, i.e., four, and actuators, i.e., three, to fulfill all the surgeon's requirements [22]; this is a major advantage over the previous designs considering the cost and maintenance issues of the system when using in clinical practices. Furthermore, there is no moving part on top of the patient body and all actuators are located at a higher level than the surgeon's head providing a larger workspace for the surgeon and clinical staff. Also, for safety reasons, the movements are stopped automatically if continued longer than 6 seconds or if the electrical motors are overloaded due to the contact of lens with body tissues or other objects. The system is equipped with a foot pedal and a voice recognition system to move up/down or left/right and zoom in/out, according to the surgeon's command.

Several technical and safety tests were conducted on the Robolens system, including manipulability, trajectory accuracy, electrical safety, etc. After these tests were successfully done, the system was tested clinically by three surgeons in Imam Khomeini Hospital during different laparoscopic procedures on human samples and the efficacy of the system was evaluated. Results of laparoscopic Cholecystectomy on two groups of patients indicated that the operating period, image stability and the number of times necessary to clean the lens improved when using the robotic cameraman. Robolens system is now in the process of commercialization and at the same time further research is being conducted to add a more sophisticated automated motion control mode to the system in which the endoscope is kept aimed at an anatomic target or track a surgical instrument by using computer vision [23].

Along the same line of thought, other research projects have been initiated in some universities to develop new robotic tools to assist the surgeons during the operation for handling difficult tasks. A novel triple finger laparoscopic instrument has been developed in RCSTIM which facilitates the grasping and manipulation of large intra-abdominal organs [24, 25]. A robotic palpation probe is developed at Amirkabir University of Technology [26]. The device utilizes artificial tactile sensing technology to provide the sense of touch for the surgeon while performing laparoscopic operations. The device has been later

Figure 4: Robolens during a laparoscopic surgery in Imam Khomeyni Hospital.

investigated to develop an automatic diagnosis tool for breast tumors. The same team has also worked on a dexterous snake-like robot to be used in minimally invasive surgeries, particularly laparoscopic surgery [27]. The device provides 5 degrees of freedom and a wide range of bending angle from -90 to 90 degrees.

Robotic tele-surgery systems

The RcSTIM has initiated a major project on the development of a laparoscopic tele-surgery system. The system consists of a master console which is operated directly by the surgeon and a set of three slave robots that perform the operation on the patient. The master console includes two master robots with a mechanical interface shaped as a standard laparoscopic surgery tool. The surgeon uses these mechanical interfaces to send the force/motion commands to the slave system. The master robots are developed to provide haptic functionality. Therefore, the surgeon receives force feedback from the robot that mimics the interacting forces between the slave robots and the patients.

The slave system consists of three spherical robots, each of which provides 4 degrees of freedom plus the grasping function of the laparoscopic tool. One of the slave robots is to manipulate the laparoscope and provide visual feedback to the surgeon at the master console. A special laparoscopic end tool is also developed for the slave robot which is fully instrumented so that automatic grasping and safe manipulation of the tissue can be implemented. Also a novel design for the grasping mechanism is employed to handle the large organs as well as the small ones. The first prototype of the tele-surgery system is fabricated and is going through the technical tests which will afterwards be followed by clinical trials on animals.

ROBOTIC REHABILITATION SYSTEMS

Robotic rehabilitation systems fall in a special subset of medical robotics which focuses on machines that are used to help people recover from severe physical trauma. These systems are generally at early stages of development and are expected to make valuable contributions to the world of physical therapy ****. However, the early results are encouraging in many cases. Robotic rehabilitation systems allow a specific task or series of tasks with high complexity to be designed and implemented on each specific patient.

The current practice of physical therapy is labour-intensive and requires one or more therapist to work with a patient to achieve the therapeutic goal. This has resulted in high associated costs which may not be affordable by the health system. A robotic rehabilitation system, e.g., a robotic gait trainer, allows rehabilitation to be performed with minimum number of therapists, with the robot providing support and tempering the patient's gait. Moreover, using force and motion sensors, the amount of patients interaction involved in these tasks are accurately measured to track his/her progress. Finally, the haptic system allows the rehabilitation tasks to be continuously updated with the progress of the patients while threshold levels are applied to ensure his/her safety.

Robotic Upper Limb Rehabilitation System

Cerebrovascular disorders and traumatic brain injuries are main causes of disabilities resulting in partial or complete motor limitation in upper and lower limbs in adults. Many researchers have investigated the upper limb rehabilitation process using different approaches, e.g., physical therapy, electrical stimulation, and passive manipulation [28, 29]. Recently, new sensory-motor rehabilitation techniques based on the use of robots and mechatronics systems have been proposed for stroke patients [30]. These techniques are claimed to improve the patient's motor performance, shorten the rehabilitation time, and provide objective parameters for evaluation of patient's progress.

The upper limb rehabilitation robotic systems usually have one to three degrees of freedom and are designed for unilateral or bilateral shoulder and elbow movements or bilateral passive and active practice of forearm and wrist [30-34]. During robotic rehabilitation, a paretic arm is manipulated, similar to a traditional physical therapy exercise, and simultaneously the speed, direction and strength of the residual voluntary activity are measured. The Gentle/s system [35], moreover, has coupled the models for human arm movements with haptic interfaces and virtual reality technology.

The RCSTIM has developed an upper limb rehabilitation device, called Wrist-RoboHab (Fig. 5) to provide therapeutic practices to the post-stroke patients [36]. It aims at decreasing the muscles spasticity, increase the power and motor control and relief the pain in the arm of chronic hemiparetic patients. Two movements with one degree of freedom, i.e., pronation/supination of the forearm and flexion/extension of the wrist, were considered.


Figure 5: Wrist-RoboHab, the robotic upper limb rehabilitation system developed at RCSTIM.

The system can function in seven working modes for patient treatment and in three working modes for patient evaluation. A graphical user interface is available for switching between working modes, as well as for adjusting the parameters and providing visual feedback for both the patient and the therapist. Furthermore, the robot can be connected to a computer via a USB port to facilitate the user communication and data transfer. Clinical results showed an improvement in Fugle-Meyer, AROM, power and the biomechanical assessment of the spasticity in a chronic patient [37]. Furthermore, it was approved that the robot can have a good interaction with both patient and therapist. Furthermore, the multifunctional feature of our robot provides the therapist with the opportunity to use it for patients with various kinds of disabilities, while making it cost-effective and affordable [38].

CONCLUSION

The emerging field of medical robotics has a major role in the future prospect of medicine. For this reason, numerous research and development projects have been initiated in this field; some of them have passed the prototyping phase and entered the clinical trials in Iran. Research activities in this field mainly focus on these two areas: robotic surgery and rehabilitation robotics.

In robotic surgery, a versatile set of projects have been initiated ranging from image-guided and computer-assisted surgery to fabricating robotic mechanisms to assist surgeon in performing the operations. A complete navigation system has been developed and introduced by the RcSTIM for ENT and brain surgeries. Several robotic tools for laparoscopic surgeries have been also developed. A complete telesurgery system for laparoscopic surgery is also under development and will soon enter the final test stages. Rehabilitation robotics is the second field of medical robotics research in Iran. Development of a robotic system for upper body physical therapy is done. The prototype has passed the technical and some clinical trials and has entered the commercialization stage.

BIBLIOGRAPHIE

[1] FARAHMAND (F.), REZAEIAN (T.) & GHAZINOURI (S.), "A comprehensive study to improve and promote the surgical device technology in Iran", *Report submitted to the Ministry of Mines and Industry of I.R. Iran*, Tehran, Iran, Feb 2003.

[2] ATESHIAN (G.A.), *A least-squares B-spline surface-fitting method for articular surfaces of diarthrodial joints*, J Biomech Eng, 115, pp. 366-373, 1993.

[3] LEE (J.H.), *Modeling generalized cylinders using direction map representation*, Journal of Computer-Aided Design, 37, pp. 837-846, 2005.

[4] JAFARI (A.), FARAHMAND (F.) & MEGHDARI (A.), Surface modeling of complicated geometries with incomplete erroneous data points-An extension to B-spline approach, *Annual International Conference of the IEEE Engineering in Medicine and Biology* (EMBS 2005), Proceedings 7 VOLS, art. no. 1616752, pp. 1634-1637, Shanghai, September 2-4, 2005.

[5] JAFARI (A.), FARAHMAND (F.), MEGHDARI (A.) & GOLESTANHA (A.S.), A new approach to C2 continuous piecewise bicubic representation of the articular surfaces of diarthrodial joints, *Proceedings of the Institution of Mechanical Engineers- Part H: Journal of Engineering in Medicine*, 220 (4): pp. 553-563, May 2006.

[6] SALVI (J.), MATABOSCH (C.), FOFI (D.) & FOREST (J.), *A review of recent range image registration methods with accuracy evaluation*, *Image and Vision Computing 25*, pp. 578-596, 2007.

[7] COLLIGNON (A.) et *al.*, *Surface Based Registration of 3D Medical Images*, Proc. SPIE Vol. 1898: Med. Imag., pp. 32-42. 1993.

[8] MOSTAFAVI (K.), JAFARI (A.) & FARAHMAND (F.), A Surface Registration Technique for Estimation of 3-D Kinematics of Joints, *The 17th Annual 'Medicine Meets Virtual Reality' Conference* (MMVR17), Long Beach, CA, USA, 2009.

[9] WANG (J.), RYU (J.), HAN (J.) & ROWEN (B.), A new method for the representation of articular surfaces using the influence surface theory of plates, *Journal of Biomechanics* 33(2000), pp. 629-633.

[10] SARKAR (S.), ABOLHASSANI (M.D.), FARAHMAND (F.), AHMADIAN (A.R.) & SABER (R.), *Research Activities at the Research Centre for Science and Technology in Medicine*, Iranian Journal of Public Health, vol. 38, Suppl. 1, pp.153-157, 2009.

[11] BASAFA (E.) & FARAHMAND (F.), Real-time simulation of the nonlinear visco-elastic deformations of soft tissues, *International Journal of Computer Assisted Radiology and Surgery*, 6: pp. 297–307, 2011.

[12] BASAFA (E.), SHEIKHOLESLAMI (M.), MIRBAGHERI (A.), FARAHMAND (F.) & VOSSOUGHI (G.R.), Design and Implementation of Series Elastic Actuators for a Haptic Laparoscopic Device, *Proceedings of the 31st Annual International Conference of the IEEE EMBS*, pp. 6054-6057, Minneapolis, Minnesota, USA, September 2-6, 2009.

[13] FUNG (Y.C.), *Biomechanics: mechanical properties of living tissues, Springer-Verlag, New York*, pp. 196-257, 1981.

[14] BASAFA (E.), FARAHMAND (F.) & VOSOUGHI (G.H.), A non-linear mass-spring model for more realistic and efficient simulation of soft tissues surgery, Studies in Health Technology and Informatics, 132: pp. 23-25, 2008.

[15] TIREHDAST (M.), MIRBAGHERI (A.R.), FARAHMAND (F.) & ASGHARI (M.), Finite element modeling of spleen tissue to analyze its interaction with a laparoscopic surgery instrument, ASME 2010 10th Biennial Conference on Engineering Systems Design and Analysis, ESDA2010, Turkey, July 12-14, 2010.

[16] TIREHDAST (M.), MIRBAGHERI (A.), ASGHARI (M.) & FARAHMAND (F.), Modeling of Interaction between a Three-Fingered Surgical Grasper and Human Spleen, *Studies in Health Technology and Informatics*, 163: pp. 663-669, 2011.

[17] ABDI (E.), FARAHMAND (F.) & DURALI (M.), Real-time 3D Modeling of Soft Tissue in Simple Interaction with Surgical Instrument Using the EGF Meshless Method, *in proceedings of 19th 'Medicine Meets Virtual Reality Conference'*, Newport Beach, CA, USA, 2012.

[18] TAYLOR (R. H.) et *al.*, *Medical Robotics and Computer Integrated Surgery*, CAS, 2(2): pp. 47-53, 2000.

[19] AIONO (S.) et *al.*, *Controlled trial of the introduction of a robotic camera assistant (EndoAssist) for laparoscopic cholecystectomy, Surg Endosc.*16(9): pp. 1267-70, 2002.

[20] KRAFT (B.M.) et *al.*, *The AESOP robot system in laparoscopic surgery: increased risk or advantage for surgeon and patient?,* Surg Endosc, 18(8): pp. 1216-23, 2004.

[21] MIRBAGHERI (A.), FARAHMAND (F.), MEGHDARI (A.) & KARIMIAN (F.), *Design and development of an effective low-cost robotic cameraman for laparoscopic surgery: RoboLens, Scientia Iranica-Transactions B: Mechanical Engineering*, 18 (1): pp. 105-114, 2011.

[22] MIRBAGHERI (A.), FARAHMAND (F.), MEGHDARI (A.) & SAYYAADI (H.), Design *of a Robotic Cameraman with Three Actuators for Laparoscopic Surgery, ASME 2006 Frontiers in Biomedical Devices Conference*, NanoBio2006, Irvine, California, USA, June 8-9, 2006.

[23] AMINI KHOIY (K.), MIRBAGHERI (A.R.), FARAHMAND (F.), & BAGHERI (S.), Marker-Free Detection of Instruments in Laparoscopic Images to Control a Cameraman Robot, *ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference* (IDETC/CIE 2010), Canada, 15-18 August 2010.

[24] MIRBAGHERI (A.R.), YAHYAZADEHFAR (M.), FARAHMAND (F.), *Conceptual design of a novel laparoscopic instrument for manipulation of large internal organs, Proceedings of ASME 2010 5th Frontiers in Biomedical Devices Conference* (BioMed2010), Newport Beach, California, USA, September 20-21, 2010.

[25] MIRBAGHERI (A.R.) & FARAHMAND (F.), *Design and analysis of an actuated endoscopic grasper for manipulation of large body organs, 32nd Annual International IEEE EMBS Conference*, art. n° 5626436, pp. 1230-1233, Argentina, August 31 - September 4, 2010.

[26] AFSHARI (E.), NAJARIAN (S.) & SIMFOROOSH (N.), *Application of artificial tactile sensing approach in kidney-stone-removal laparoscopy, Biomedical Materials and Engineering*, vol. 20, n° 5, pp. 261-267, 2010.

[27] KHOORJESTAN (S.M.), NAJARIAN (S.), SIMFOROOSH (N.), & FARKOUSH (S.H.), Design and Modeling of a Novel Flexible Surgical Instrument Applicable in Minimally Invasive Surgery, *International Journal of Natural and Engineering Sciences 4* (1): pp. 53-60, 2010.

[28] FEYS (H.M.) et *al.*, *Effect of a therapeutic intervention for the hemiplegic upper limb in the acute phase after stroke: A single-blind, randomized, controlled multicenter trial, Stroke,* 29(4), pp. 785–792, 1998.

[29] KWAKKEL (G.) et *al.*, *Intensity of leg and arm training after primary middle cerebral artery stroke: A randomised trial*, Lancet, 354: pp. 191–196, 1999.

[30] DIJKERS (M.P.) et *al.*, *Patient and staff acceptance of robotic technology in occupational therapy: a pilot study.* REHABIL (J.) Res Dev, 28(2): pp. 33-44, 1991.

[31] JOHNSON (M.J.) et *al.*; Driver's SEAT: *Simulation environment for arm therapy. in International Rehabilitaion Robotics.* Stanford, 1999.

[32] LUM (P.S.), BURGAR (C.G.) and SHOR (P.C.), Use of the MIME robotic system to retrain multijoint reaching in post-stroke hemiparesis: why some movement patterns work better than others, *Proceedings of the 25th Annual International Conference of the Engineering in Medicine and Biology Society IEEE.* 2003.

[33] BURGAR (C.G.) et *al.*, *Development of robots for rehabilitation therapy: the Palo Alto VA/Stanford experience.* REHABIL (J.) Res Dev, 37(6): pp. 663-73, 2000.

[34] KREBS (H.I.) et *al.*, *Rehabilitation robotics: pilot trial of a spatial extension for MIT-Manus.* NEURO-ENG REHABIL (J.), 1(1): p. 5, 2004.

[35] LOUREIRO (R.) et *al.*, *Upper Limb Robot Mediated Stroke Therapy-GENTLE/s Approach. Autonomous Robots*, 15(1): pp. 35-51, 2003.

[36] RASHEDI (E.), MIRBAGHERI (A.), TAHERI (B.), FARAHMAND (F.), VOSSOUGHI (G.R.) & PARNIANPOUR (M.), Design and Development of a Hand Robotic Rehabilitation Device for Post-Stroke Patients, *Proceedings of the 31st Annual International Conference of the IEEE EMBS*, pp. 5026-5029, Minneapolis, Minnesota, USA, September 2-6, 2009.

[37] BANIASAD (M.A.), FARAHMAND (F.) & NAKHOSTIN ANSARI (N.), Wrist-RoboHab: A Robot for Treatment and Evaluation of Brain Injury Patients, *International Conference on Rehabilitation Robotics* (ICORR 2011), Zurich, June 29–July 1, 2011.

[38] BANIASAD (M.A.), AKBAR (M.), ALASTY (A.) & FARAHMAND (F.), *Fuzzy Control of a Hand Rehabilitation Robot to Optimize the Exercise Speed in Passive Working Mode, Studies in Health Technology and Informatics*, 163: pp. 39-43 2011.