Haptic Feedback in Surgical Robotic Applications – A Review

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Abstract-

In today's medical practices, endovascular procedures have become increasingly popular. *Compared to that of traditional surgical procedure, robotic surgical system is providing higher precision and the ability to control more efficiently from a remote position. But, total feedback that is, force feedback and tactile feedback cannot be provided by these robotic systems in real time applications. The role of haptic feedback is discussed under this review paper and a brief discussion about various medical technologies and medical applications. Touch and kinesthesis are precious, effortless senses that are most important for rapid and accurate interaction with the surroundings. This review compresses the viewpoints that have to be considered in the deployment of haptic technologies in medical training. The advancements in this haptic feedback field in robotics, encourages the overall surgical procedures that are frequently coordinated with visual feedback capability. Haptic technology is better spoken to in virtual reality. Test systems for preparing surgical mediations. Yet in addition, extra endeavors are expected to enhance the realism of the communication. Without guaranteeing the completeness, this paper gives a wide outline of haptic feedback for medicinal applications and demonstrates some current patterns in this field. Through this paper, a review for minimally invasive surgeries and their comparing advancements are introduced.*

Keywords: *Degree of freedom, force feedback, haptics, Robot assisted minimally invasive surgery, surgical robot, tactile feedback.*

INTRODUCTION

Robot assisted minimally invasive surgery (RMIS) reduces the chances of trauma to the patients and improves accuracy. However, there is marginal success with RMIS. Existing RMIS designs are not commercial as it is not much useful to provide complete feedback i.e., with visual feedback it should also be capable of providing force feedback and tactile feedback. The robotic surgical framework, for example, Da Vinci surgical framework, joins the important points from minimally invasive surgery that incorporate decreased chances of infection or diseases, less pain, shorter doctor's facility stay and lower general medicinal services costs. Furthermore, these automated frameworks additionally enhance the adroitness, eliminates the surgeon's tremors and decreases the surgeon's exhaustion. However these automated surgical frameworks likewise have some drawbacks, for example, their underlying high cost, special training is necessary for specialists and absence of precise haptic feedback to the surgeon [1,2].

There are a few difficulties with minimally invasive surgery (MIS) for example restricted perspective or surgical work space, challenges in handling of surgical tools through small cuts, adroitness and absence of haptic feedback [3,4]. These limitations can be resolved with robotic surgical assistants (RSA). These robots are becoming more popular due to the capability in improving dexterity, motion scalability and filtering surgeon's tremors [5]. A study by Wagner et al. [13] showed the performance of the RSAs can be greatly improved with force feedback. Haptic technology has shown the potential to restore tangibility to human computer interaction; the spread of haptic devices in numerous fields appears to be inevitable. Haptic feedback has been employed to transform several tasks by providing auxiliary sensory channels [7].

Various surgical procedures like urologic, cardiac and thousands of general surgeries were performed in the last few years with robotic surgical system. The main research area in robotic surgery seeks to transfer the force applied by the physician during the procedure provided as a feedback so that the physician can get the idea how much force is required to be applied on a particular part. This requires the integration of haptic sensors into the instruments utilized by surgical robots for showing haptic data to the human operator. When this is refined, various clinical opportunities will emerge [8]. This lack of haptic feedback limits the procedures that can be done robotically, as surgeons cannot feel how hard they are pulling a suture or tactilely localize occlusions within tissue. It therefore seems appropriate that the majority of the research from the haptics community has focused on developing commercially viable haptic feedback systems [9,10,11,12]. Various researches are going on to overcome the lack of haptic feedback and are focusing on the practical implementation in different fields like medicine, training, dentistry, etc. While some of them indulged in creative ideas and more have made it into the operating theatre in a permanent food and drug administration (FDA) approved capacity.

MINIMALLY INVASIVE SURGICAL ROBOT TECHNOLOGIES

A. From Conventional to Robotic Surgery

High precision and repeatable movement can give significant advantages to the vast majority of the first generation of medical robots that were intended for MIS tool positioning [17]. These positioning tools are huge in MIS as these strategies are harder to perform; these kinds of robots basically diminish the fatigue of the surgeon during the procedure [18]. Orthopedic surgeries were the essential kind of medical procedures for which robots were created with specific functionalities required to play a dynamic part in an operation. Tremendous numbers of robots were made in 90s for orthopedic surgeries and this was to mechanize some portion of procedure during the surgery. These modernized and dynamic robots would execute a preoperative imaging method. It was seen that the use of robots in this plan would improve the general consequence of a surgery through extended accuracy embed position. In 1980s, ROBODOC progression began and advancement in human trials in 1922 demonstrated critical change of the surgical outcomes picked up by utilizing this framework over human directed surgery [19].

B. Robot Assisted Minimally Invasive Surgery

Tissue deformability was found as a reason of particular challenges like to use the automated robotics to delicate tissues [20]. This means that the imaging registration process is insufficient to compare the robots with the patients from the images taken before operation. So, as a solution either deformable tissue models or intra-imaging can be used with the preoperative planning [21,22]. Another issue with this automation system or automated robotics is that, it is not completely safe as the robotics artificial intelligence is not so developed or progressed to the degree where robot can be committed capable if the error is made.

This led to the shifting of automated to non-automated telerobotics systems. These telerobotics systems are master slave type platform in which the surgeon can control directly the robotic manipulator. Most of the advanced and sophisticated examples of this telerobotic system are the Da Vinci robot of intuitive surgical Inc., Titan medical Inc. Amadeus system, and the ZEUS of computer motion Inc.

C. Parallel Mechanism Surgical Robotics

A large portion of automated controller is serial structures which are used for both invasive and non-invasive medical treatments. The benefit of using these serial structure robots is of high adroitness, an extensive counter or workspace and greater mobility. However, they experience low firmness and lower situating precision. To identify the disadvantages related to serial structures, more considerations has been paid to parallel structure robots in view of their extensive pay load limit, effortlessness and positional exactness. The very first parallel platform was developed by Stewart in 1965 [23], which composed of a well settled base, a versatile stage and six actuators of variable length associated with base and stage. Parallel structure robots have been developed in recent years for variety of medical procedures. Tanikawa and Arai built up an adroit miniaturized scale control framework in view of a parallel system and used it for performing microsurgery among a couple of different undertakings [25]. In 2003, Shoham et al. built up a smaller than a usual robots named as MARS, for surgical methodology, a barrel shaped instrument with 6 degree of freedom (DoF), and utilized as a part of assortment of some surgical techniques like trauma and spine surgery [26]. For neurosurgical activities, Tsai and Hsu [27] developed a surgical robot based on parallel structure topology for exact skull penetration. Bradt et al. [24] built up a parallel structured robot with a Computational Centre for various surgical intervention arrangements and for controlling the stages simultaneously, this robot is named as CRIGOS (Compact robotic system for image guided orthopedic surgery). More recent advancements in the utilization of parallel structures for medical interventions incorporate the work by Fine et al. [14], in which composition of ophthalmic surgical robot with double arm with parallel structured instrument is used (figure 1) with improved precision (<5µm). Nowadays, the parallel structured robots are used and composed for needle surgery by various different groups, also includes a dynamic model i.e., “Pmar needle” and its control [28].

The essential space for task, storage and for proper movement rearrangements of the robot in the working room can be accessed by using a parallel structured medical robot. But, restricted workspace is a major drawback in case of parallel structure as compared to serial structure. Parallel structures can provide high precisions if designed correctly.

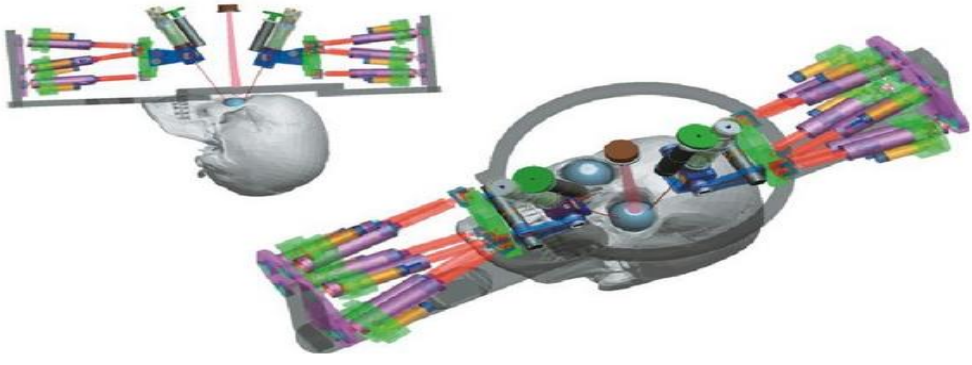

Fig. 1. Dual Arm Robot for Ophthalmic Surgery [14].

D. Wireless Robotic System

Another branch comes into sight due to the mechanical structures that can reach far inside the human body in minimally invasive surgery. Numerous cases of this structure related applications are found in gastrointestinal (GI) techniques. With conventional GI endoscopic procedures patients complained pain and discomfort. This has been overcome to a large extent with robotic device such as Pillcam as shown in figure 2 that can be inserted into GI tract and can be operated [29]. By the use of robotic devices, the discomfort and pain reduces to a great extent. Also the cause of infection, blood loss, hospital stay and trauma reduces very much by the use of robotic devices.

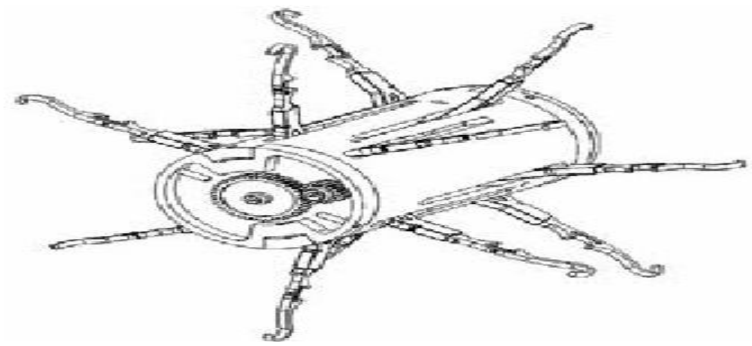

Fig. 2. Pillcam for Gastro-intestinal (GI) Endoscopic procedures [29].

Requirement Of Haptic In Minimally Invasive Surgery

In the field of research, medical haptics is developing slowly and gaining a great attention. [30]. The inspiration is mainly from its devices used as a tool and also in the teleoperation development [31]. To bring haptic feedback to medical tools, various researches are going to improve the performance in MIS surgery. Over years, around 15 or 20, haptic feedback is used either for medical training or for improving the medical procedures using surgical tools by providing force feedback [33].

A. Surgical Training and Simulation

Haptic surgical simulators have improved the overall training procedure to a great extent, as with the help of surgical simulators, one can develop a virtual environment to teach technical skills, procedures and operation [32], rather than the surgeon or specialist study the anatomy from coarse readings and other visual guides and after that "hands on" preparation in the operation room by cadaver dissection or dead body analyzation [34].

B. Haptic Feedback in Telerobotic Surgery

With the ascent of teleoperated minimally invasive surgery, haptic input has turned into a great area of research. Touch and kinesthesis are subtle, effortless senses that are basically essential for quick, exact communication with our environment. Clinically, such feedback can improve the overall work performance as increase in the surgeon's sense of telepresence. The effect of the loss of these feedback forces become clear by observing the lives of the people affected by somesthetic loss. The use of this haptic feedback has strongly made a dexterous change in the overall procedure. As in the Da Vinci surgical system, safe cardiac surgical procedures can be done using haptic feedback [35]. But this deficiency in this area handicaps the telerobotic MIS as it may lead to unsafe level of force by surgeon or clinician [37], as like in open surgery, surgeons heavily rely on touch e.g., palpation of tissue to distinguish between healthy and unhealthy tissue.

An interval between independent medical robotics autonomy and master slave telesurgery, a zone of surgical haptic gives the utilization of "virtual fixtures" [38]. Such robots don't effective drive the apparatuses being utilized; rather the specialist's own thought process control is utilized, while the controlling forces can be provided by the robots. When the work space is reached on the boundary, the controlling process force can be provided by the robots. This approach of work in robot assisted surgery and MIS technique provides safety and complete control on commands to the surgeon [39]. The advancements of haptic capacities for telerobotics framework (Da Vinci, Black Falcon) has become another research zone with critical ascent in popularity.

The Black Falcon is capable in 8-DoF and was created at MIT [Massachusetts Institute of Technology] in late 90's [40], which helps to improve the surgeon's facility to a great extent during an interventional procedure. Some limitations of MIS are used to remove by using the Black Falcon. These limitations may include inconsistency between motion of tools via endoscope, lack of adroitness during procedure due to lack of tactile or force feedback. There is used to implement force reflection on the master side using PHANTOM.

Another workstation was developed named as robotic telesurgical workstation (RTW) [15] basically for suturing and knot tying. The improved version of this design has 6-DoF PHANTOMs given for slave manipulator particularly. The slave consists of two main sections, a 4-DoF laparoscopic grasper and 2-DoF Endo-wrist. This advanced design shows that due to process of force feedback, suturing and knot tying task become much easier as compared to that of when no feedback was there. Haptic feedback lacks in telesurgery was also shown by Okamura [36]. The increase in the duration of operation with more chances of error can be cause by lack in haptics. Because of the trouble in making appropriate force sensors, current telerobotic frameworks still do not have the haptic feedback [41]. Also, the difficulty in the adjustment to the complex end effectors causes trouble in haptic feedback.

C. Tactile sensing devices

The procedure performance can be increases by force feedback [13]. So, full frame force feedback is an important research criterion which include this tactile feedback, and enhancing this tactile sensing capability has turned into a prime research zone [42]. As Okamura also argued that for true telemanipulation both force feedback and tactile feedback will be required. Development of these tactile sensing devices is due to the failure of the clinicians to palpate the tissue stiffness, to detect whether the tissue is healthy or not [43, 44]. As per an audit conducted by Benali-Khoudia [45], all the physical parameters are not displayed completely tactile. Tactile sensing devices are still too large, expensive, and imprecise to be used in MIS. Force feedback devices are much more developed as compared to that of tactile sensing devices.

Langrana et al. [46] produced one of the palpation simulations by utilizing a virtual knee demonstrate and Rutgers master for feedback force information. A glove with actuators that are set proximal to the arm were the Rugters master. The complete information about bones, cartilages and muscles was comprises with the developed knee model. By using Hooke’s law, the tactile or contact forces was calculated and also fed to the master for real time applications. The main drawback was to simulate the object weight due to the present of wrist feedback.To allow the surgeons to palpate a region to locate a muscle and arteries become the main objective of research. It can detect the blood flow similarly as in open surgery, and this requirement gives the motivation for the development of the first haptic medical system in Bio- robotics lab at Havard for laparoscopy by Peine et al. [47]. A long endoscope like probe device is shown in figure 3 which comprises a tactile sensor array situated towards the end. The testing is the last portion which is adaptable and enables the specialist to control the tip in the region of operation by a trigger component.

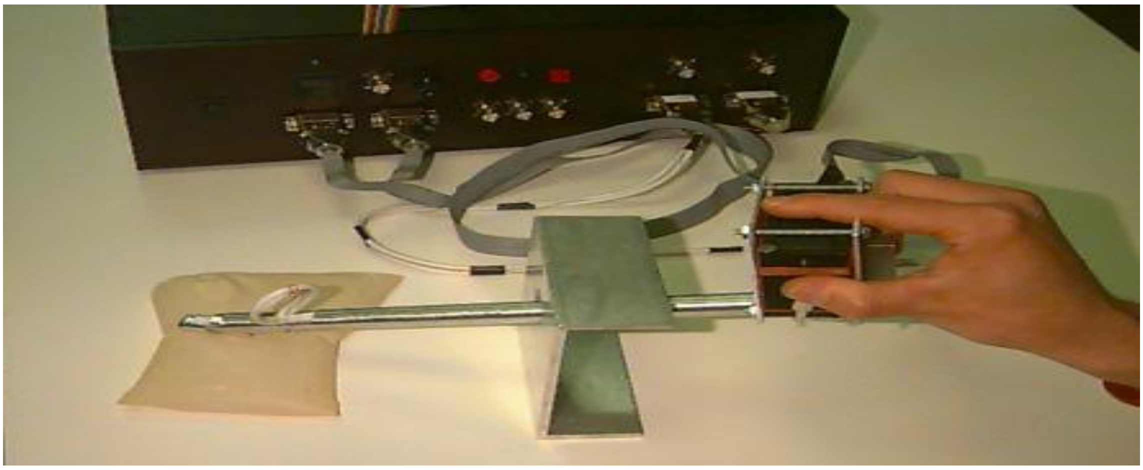

Fig. 3. Palpation and display device [47]

P.S Wellman et al. [48] developed a new device as shown in figure 4, named as “tactile imaging”. For the examination of lumps of breast, this device was designed for the stiffness of an anatomical region. In case of manual palpation to detect new masses and changes in the breast texture, physical examination might be troublesome. The device consists of 16 rows×26 columns array of piezoresistive pressure sensors with 1.5 mm resolution which are twice accurate as compared to manual examination or ultrasound exams. J. Dargahi et al. [16] has developed an endoscopic grasper (figure 5) with inbuilt sensor to sense the applied force on a particular tissue and collect it as a current feedback to the display, i.e. visual force feedback functionality is there.

An efficient data interpretation system was designed by M.I Petra et al. [49] at the University of Birmingham. It includes various processing units i.e., artificial neural network (ANN), real time digital signal processing and advanced FPGA based applications, distributive tactile sensing technology. So, that it can be used in a steerable endoscope to fetch the information about touch and shape. The design is so developed using PVC (Poly-vinyl chloride) tubes with varying ruggedness throughout the longitudinal cross section. This was shown that the cascade architecture could achieve an overall accuracy of more than 94 percent. This was done through a survey done on diverse arrangements of signal interpretations such as single and cascade neural networks. This technology can discriminate the palpation and contact in MIS.

A laparoscopic grasper was designed at the institute of health care university, Germany [50]. Which was different from the conventional graspers as its jaws has inbuilt sensor (strain gauge sensor) and the output is graphed on a 2-Dimensional color map but the only drawback is that, all the tissues are not graspable. Bicchi reported the development of a haptic device in the ARTS lab in the University of Pisa. The sensing units were added and located near the handle. Force sensor is used with two strain gauges and the feedback is given to the surgeon as visual feedback via monitor display. This feedback helps in providing the feeling of touch on the fingers.

In general this is the haptic feedback technology which is gaining a high attention of researchers. The limitation of this device causes backlash and friction. It may affect the feedback which is measured by the sensors position and the apparatus properties.

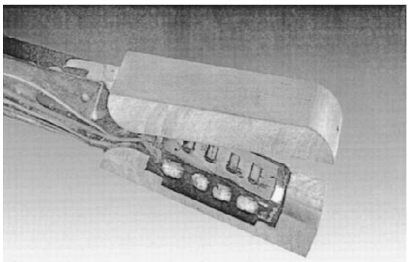

Fig. 5. Endoscopic grasper [16]

Fig. 4. Scan head of tactile imaging [48]

CONCLUSION

This article gives a brief and rather deficient overview of the utilization of haptic feedback in medical applications. As the enthusiasm for this field is gathering momentum, a few new gadgets and items will probably show up in short or middle term. New advancements in sensor innovation, a superior comprehension of adaptable robot control and advance in coordinating cutaneous and kinaesthetic senses are just a portion of the regions where extra research is required and that could prompt new and interesting applications.in the field of haptic innovation and neuroscience, some new advancement can be more effective. To achieve these objectives, researchers need to create and test a proper haptic technology for RMIS (Robotic assisted minimally invasive surgery).

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