Chapter 81
Telesurgical Robotics and a Kinematic Perspective

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ABSTRACT

Minimally invasive surgery (MIS) has revolutionized the world of surgery. On one hand, it offered many revolutionary advantages; on the other hand, it proved to be a tedious and sophisticated technique for surgeons. Telesurgical robotics came forward to assist surgeons and made surgeries even further innovative, safer, and efficacious. Kinematic—a fundamental and foremost design step—acts as the lynchpin of performance of a surgical robot. It plays a decisive role and defines the capabilities and viability of a robot vis-à-vis its application. This chapter tries to understand the kinematic design approaches in practice so far and discusses their features and potential shortcomings. Some of the notable kinematic structures are explained in detail, and an all-inclusive consideration to the kinematic aspects of the existing designs has been given. Based on the key challenges identified, possible solutions are suggested, which is followed by future research directions and conclusion.

INTRODUCTION

The advent of Minimally Invasive Surgery (MIS) in surgical theaters has revolutionized the centuries-old art of surgery for various surgical procedures. After rapidly gaining its momentum in 1990s, MIS offered huge benefits over the traditional open-surgery techniques. Details of which can be found in (Satava, 2004; Lanfranco, 2004; Holt, 2004; Taylor, 2006; Kuo C. H., 2009; Nisar, 2015). Along with its revolutionary advantages, MIS proved to be a tedious and cumbersome technique for surgeons. For safety and better efficacy, it requires well-trained and skillful surgeons to carry out the surgical procedures. When compared with open-surgery, MIS techniques adversely affect surgeons' ability of direct-sight, sense-of-touch, depth perception and kinesthetic feel. These issues, along with numerous others pose serious challenges to medical doctors and surgeons when performing MIS procedures.

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Surgical robotics, primarily, emerged as a very effective solution to the above-mentioned problems and many other related issues. With the passage of time, these robots started taking the role of augmenters and led to the emergence of many innovative, safer, better and user-friendly features pertaining to various MIS procedures. This gave huge impetus to the ongoing research in this field and grabbed a lot of attention from researchers of many mutually varying fields of research. While industry has played an important role, it had been the academia that remained at the forefront of the research in surgical robotics. Being in operation theaters for roughly more than two decades, surgical robots have demonstrated their potential towards the betterment of surgical procedures and general degree of efficacy (Taylor, 2006; Nisar, 2015). Enhanced precision, greater control over maneuvers, scalable movements and tremor-free tool motion with tactile feedback are some of the sublime features of today's surgical robots. Increased trust of surgeons, medical practitioners (Chitwood, 2001) and, even of the patients, on the use of robots for medical and surgical purposes is becoming a hallmark of this technology. With every new development, the overall size and weight of surgical robots is shrinking while the reliability and safety margins are expanding.

Behind every successful surgical robot, a number of technical and non-technical factors play an important role. For example, kinematics, dynamics, control and manufacturability are some of the technical aspects of a design. Kinematics - being the first and foremost manipulator design step - is considered as the lynchpin of performance for any surgical robot. It is a fundamental aspect of any mechanical design (Kuo C. H., 2012) and plays a decisive role in ascertaining its capabilities and viability vis-à-vis applications. A sound kinematic design is better posed to offer greater performance measures in terms of safety, reliability and surgical task-achievement (Kuo C. H., 2009). Kinematic design acts as a foundation block for the rest of surgical robotic system to be built over. A dismal kinematic design could severely limit the capabilities of a robot for advanced features and vice versa. Therefore, it is important to understand the kinematic design approaches in practice so far and discuss their features and potential shortcomings.

A number of well-researched and peer-reviewed surgical robots in academia and industry for various minimally invasive surgical procedures have been proposed and many novel designs are being continuously investigated. Thus a survey of the kinematic aspects of these existing designs, giving an all-inclusive consideration, can play a vital role in understanding their pros and cons and thus improving performance of the new designs.

BACKGROUND

Most of the existing surgical robotic systems are telesurgical in nature, where the surgeon operates robotic tools remotely (Nisar, 2015). This remote location could be the same room as that of the patient or anywhere outside. Given the extensive focus on telesurgical systems, the terms 'surgical robotics' and 'telesurgical robotics' are sometimes implied in the latter's sense despite of a certain distinction between the two.

A typical telesurgical robotic system constitutes of various subsystems, like master manipulator, slave manipulator, surgical tool with wrist, control unit and vision system. A system level explanation of a particular surgical robot is described at length in (Hassan, 2014). One key member, and a more interesting one from the robotics perspective, is the slave manipulator. Every manipulator is built upon some mechanism, which embodies the concept and ingenuity of its designer to achieve some specific task, for example, surgical tool movement in the case of surgery. This ability of a mechanism to achieve