Medical Robotics:
State-of-the-Art Applications and Research Challenges

Alireza Mirbagheri, RCBTR, Tehran University of Medical Sciences, Tehran, Iran

Mina Arab Baniasad, School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran

Farzam Farahmand, RCBTR, Tehran University of Medical Sciences, Tehran, Iran & School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran

Saeed Behzadipour, School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran

Alireza Ahmadian, RCBTR, Tehran University of Medical Sciences, Tehran, Iran

ABSTRACT

Many research and development projects are being performed worldwide to develop new products and applications for computer-assisted and medical robotic systems. In this paper, an overview of selected state-of-the-art applications of robotic technology in medicine is presented. Four key areas of image-guided surgery, virtual reality in medicine, surgical robots, and robotic rehabilitation systems, are studied. As well, current challenges in research and development are discussed.

Keywords: *Image-Guided Surgery, Medical Robotics, Robotic Rehabilitation, Robotic Surgery, Virtual Reality in Medicine*

INTRODUCTION

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

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many different computer-related technologies. Modern medical imaging systems, such as CT, MR, PET, together with advanced techniques of image processing and modeling, 3D anatomy visualization, real-time tracking and sensing, haptics and robotics are considered to be the key underlying technologies.

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

In the medical robotics lab of the Research Center of Biomedical Technology and Robotics (RCBTR), we have worked on a variety of research projects in different fields of medical robotics, in partnership with several clinics and medical centers (Farahmand, Amirnia, Sarkar, Behzadipour, Ahmadian, & Mirbagheri, 2012). A wide range of clinical problems were indentified and appropriate technologies were pursued, mainly in four key areas of image-guided surgery, virtual reality in medicine, surgical robots, and robotic rehabilitation systems. This article provides an overview on the applications of robotics in medicine, with emphasis on the projects performed and experiences gained by our team in the field.

IMAGE-GUIDED SURGERY

Surface Modeling

The development of powerful medical imaging systems and the need for 3D geometrical models for surgical applications has brought a new perspective to the anatomical modeling in recent years. Modern medical imaging systems, e.g., MRI and CT, 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 need to be further processed through continuous mathematical representation to produce 3-D visualizations for computer pre-planning 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 the 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 modeling. The smoothing process is essential since the experimental data generally contains a degree of error, leading to the creation of ripples in the model, especially 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 ripple effects. The surface modeling 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 (Ateshian, 1993).