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Mechanism and Machine Theory 43 (2008) 1186–1197
Mechanism and Machine Theory
www.elsevier.com/locate/mechmt

Conceptual design and dimensional synthesis of "MicroHand"

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Received 3 July 2006; received in revised form 8 July 2007; accepted 4 August 2007
Available online 23 October 2007

Abstract

A master–slave surgical robotic system can make the best use of both a doctor's experience and the characteristics of precise positioning, stable performance and dexterous manipulability of a robot. A new surgical robotic system "MicroHand" is presented in this paper with a master–slave isomerous mechanism to provide more design freedoms. The master of "MicroHand" is a Phantom Desktop device and the slave manipulator is a system designed using a position mechanism and an orientation mechanism. The position mechanism implements the kinematic characteristics of a double parallelogram mechanism driven by a cable, which can decouple the position and posture of the slave manipulator. The orientation mechanism applies three rotating axes intersecting at one point to ensure that the surgical tools have enough dexterity at any position in the workspace. The position mechanism and its parameters are designed based on kinematic analysis of two cable-driven linkage structures and kinematic conditioning index. The suitable positions are analyzed in the workspace of a single arm and also in the coworkspace of the two arms. The optimal results show that the "MicroHand" system can enhance the ability of the surgeon in a blood vessel (1 mm in diameter) suturing and knotting experiment.

Keywords: The "MicroHand" system; Medical robot; Cable driven; Mechanism optimization

1. Introduction

Micro-surgery requires a surgeon to perform fine operations such as the connection of blood vessels and nerves that are less than 1 mm in diameter. Such operations are currently executed manually by a doctor under a microscope. Generally speaking, tasks that require precise and controlled motions are difficult for most doctors who do not have any long-time practical experiences. In addition, the precise operations may cause an extreme stress on the doctor. Therefore, surgical robotic systems have been under development in order to extend the human capability by using master–slave or tele-robotic principles. Medical robots are currently applied in neurosurgery, micro-surgery and minimally invasive surgery(MIS) [1,2]. The most famous surgical robot system is Da Vinci [3] for MIS. Several other systems for micro-surgery have also been developed [4–10].

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doi:10.1016/j.mechmachtheory.2007.08.003

Most of the surgical robotic systems adopt the master–slave control mode. The operator can reside in close proximity to the slave manipulator, or stay many miles away from the operation site [1,6,10,11]. Generally, the surgical robotic systems in master–slave mode are mostly designed with isomorphic mechanism, which can be easily designed and controlled [12]. However, the maneuverability of the present isomorphic master–slave systems seems still far from satisfactory. The problem lies in how the master can be made more comfortable and "realistic" for the operator and how the slave manipulators can be made "optimal" for operation environment at the same time.

In this research, a new surgical robotic system named "MicroHand" [13] is developed.. "MicroHand" is designed as a master–slave device with an isomerous mechanism. The master of "MicroHand" is a Phantom Desktop device, which is a commercial haptic interface with high stiffness, low friction, low inertia, high precision and good haptic capabilities. The slave manipulator of "MicroHand" is designed and optimized for suturing and knot-tying micro-vessels. This paper focuses on the mechanism design, dimensional synthesis and configuration of the surgical workspace of the "MicroHand" system.

The remainder of the paper is organized as follows. Section 2 presents the mechanism design of "MicroHand". Section 3 optimizes the dimensions of the mechanism. The configuration of the surgical workspace is analyzed in Section 4. An example is showed in Section 5 and conclusions are drawn in Section 6.

2. Design of "MicroHand" mechanism

In this section, mechanism design of the slave manipulator of "MicroHand" is discussed.

2.1. Description of the "MicroHand" system

The "MicroHand" system is designed as master–slave manipulators with various changeable surgical tools and a multi-view image system, as shown in Fig. 1. The master manipulator is the commercial haptic interface (Phantom Desktop). The slave manipulator consists of two arms, the left arm and the right arm. The two arms have the same structures and are installed on each side of the column of the microscope system. Each arm has a coarse motion mechanism with 2 DOF (joint 1, and joint 2) and a fine motion mechanism with 6 DOFs (joint 3 to joint 8). The coarse motion mechanism provides a large workspace and is used to move the operative tools into the surgical fields rapidly, while the fine motion mechanism is designed for the realization of precise operations. The fine motion mechanism of the slave manipulator is controlled by the master manipulator. The force acting on the slave robot is measured with the Mini40 force/torque sensor installed at the end of the slave robot. As a new micro-surgical robot system, the MicroHand is an isomerous system, which can be widely used for such surgeries as micro-surgery and minimally invasive surgery (MIS). Because of the different mechanical structure of the master and slave robots, the six degrees of freedom of the slave robot and those of the master robots are corresponding to (non single-joint correspondence) each other in position and gesture by the model of kinematics. The corresponding coefficient of the gesture is 1, which can provide the same

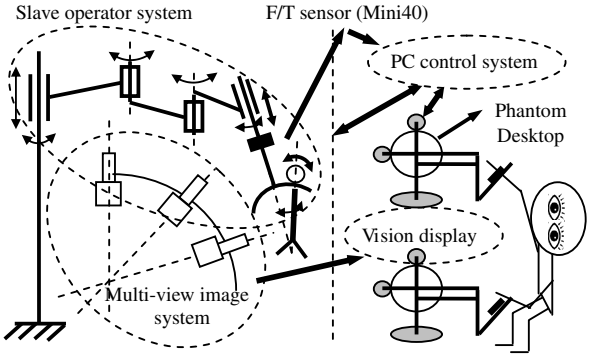

Fig. 1. The scheme of the "MicroHand" system.