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Review on Design of Compliant Mechanism for Surgical Applications

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Abstract

Compliant mechanisms are joint less mechanisms that rely on elastic deformation to transmit forces and motion. The lack of traditional joints in these single-piece flexible structures offers many benefits, including the absence of wear debris, pinch points, crevices, and lubrication. The topic is concerned with the benefits of exploiting elasticity in the engineering design of surgical tools, in general, and of minimally invasive procedures, in particular. Such systems are particularly amenable to embedded sensing for haptic feedback and embedded actuation with active material actuators. The paper consists of overview of design synthesis methods developed at the Compliant Systems Design Laboratory and focuses specifically on surgical applications. Compliant systems have potential to integrate well within the constraints of laparoscopic procedures and telerobotic surgery. Compliant mechanisms offer numerous advantages over their rigid-body counterparts. The synthesis with compliance technique synthesizes compliant mechanisms for conventional rigid-body synthesis tasks with energy/torque specifications at precision positions.

Keywords*— Compliant Mechanism, Topology optimization, Distributed compliance, Flexibility, Stiffness*

I. INTRODUCTION

Distributed compliant mechanisms are flexible structures that use strain energy to transform input energy components into a desired output force or displacement. Compliant mechanisms are monolithic structures and require no assembly; therefore they are very well suited for micro fabrication. The compliant mechanisms are functionally similar to the rigid-body mechanisms but they gain some or all of their mobility from the deflection of flexible members rather than from movable joints only. The term compliant mechanism refers to a larger field that includes living hinges and flexures. Definition of a compliant mechanism is a device that uses the distributed compliance of its structure to achieve mechanical tasks, such as force/motion transmission, without the use of conventional mechanical joints or living hinges. Designs in nature are strong but not necessarily stiff; they are compliant and often have embedded actuation and sensing capabilities. Engineered devices, on the other hand, are traditionally designed to be strong and stiff. By assuming individual components to be infinitely rigid, engineers create complex assemblies to perform electromechanical functions and then deal with problems due to wear, backlash, and noise in order to meet precision, cost, and reliability requirements. However, many practical benefits can be realized by exploiting elasticity with a unique opportunity to create monolithic compliant mechanisms with embedded sensing and actuation. The simplest example of compliant mechanism is the bow, shown in figure 1 used to shoot arrows.

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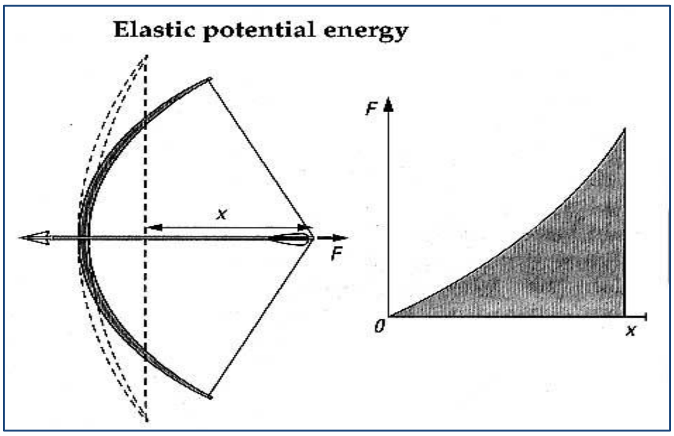

Fig. 1 A bow (shown above) is a compliant mechanism since it uses deflection to store elastic potential energy like a spring and the energy is transferred as kinetic energy to an arrow.

II. WORKING PRINCIPLE

Traditional rigid body mechanisms consist of rigid links connected at movable joints and are capable of transforming motion and forces. A rigid mechanism does not have mobility, so it does not perform any work by storing energy, it simply transfers energy. Since energy is conserved between the input and output, the output force may be much larger than the input force (mechanical advantage), but the output displacement is much smaller than the input displacement (geometric advantage) or vice versa. Compliant mechanisms rely on the deflection of flexible members to store energy in the form of strain energy. This stored energy is similar to the elastic potential energy in a deflected spring. An ideal compliant mechanism is designed to conserve energy. Thus a compliant mechanism serves as a transmission that converts the input energy in a controlled way. Since energy is conserved the product of force and displacement remains constant.

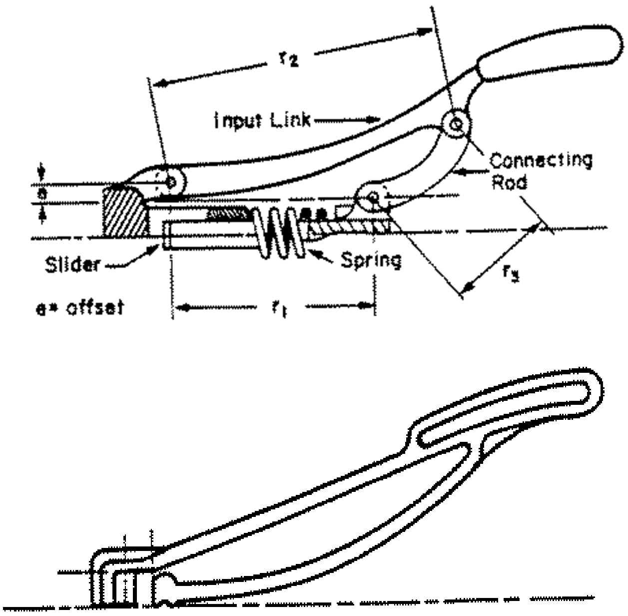

Fig. 2 Traditional Mechanism and equivalent compliant mechanism

III.DESIGN OF DISTRIBUTED COMPLIANT MECHANISMS

A. Pseudo Rigid Body Model

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A pseudo-rigid-body model accurately simulates the deflections of flexible members using rigid-body members and torsional springs having equivalent force-deflections characteristics. It enables the simulation of complicated non linear elastic structures by using well established and simpler simulation techniques. It can be shown that free end of the flexible cantilever beam with force at the free end follows a nearly circular path, having some radius of curvature along the beam's length. This idea is used to develop the parametric approximations for the beam's deflection path, wherein it is assumed that nearly circular path travel of beam's end can be modeled by two rigid links joined at characteristic pivot along the beam. The characteristic pivot location on the beam is measured as a fraction of beam length from the beam end. This fractional distance is known as characteristic radius.

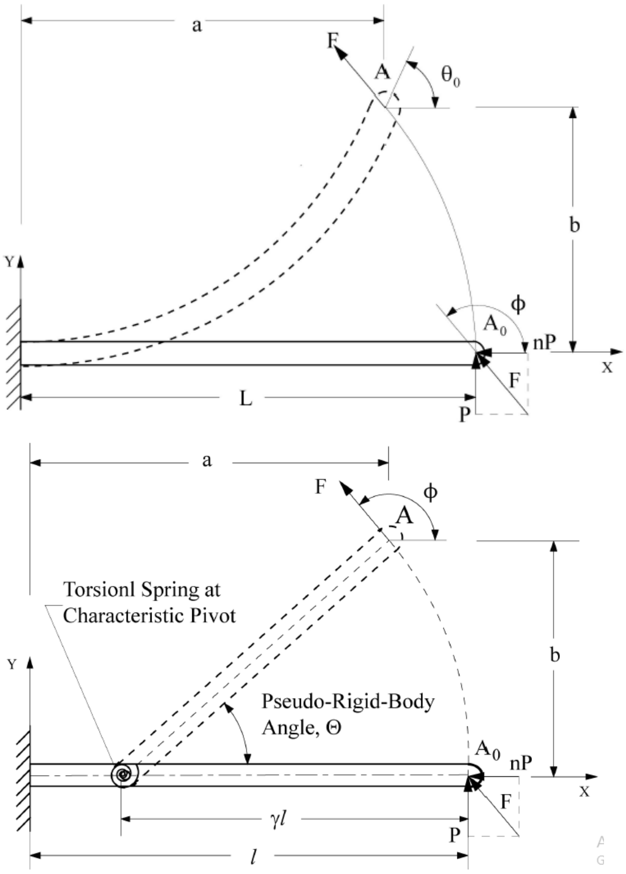

Fig. 3 Generation of Pseudo Rigid Body Model

There are two basic steps in the design of compliant mechanism

1). Topology Synthesis:

To construct a kinematic geometry that generates the desired displacement and force output for a given input.

2). Size and Shape Optimization:

In this step the shape of the individual elements is optimized to ensure that the mechanism achieves prescribed performance specifications. Performance specifications include prescribed geometric or mechanical advantage, minimization of energy losses in the mechanism, and output phase or resonant frequency for dynamic loading.

B. Procedure for Topology Synthesis

1) *Develop:* A basic block structure which will serve the objective function i.e. Provide the desired output motion and forces with given input.

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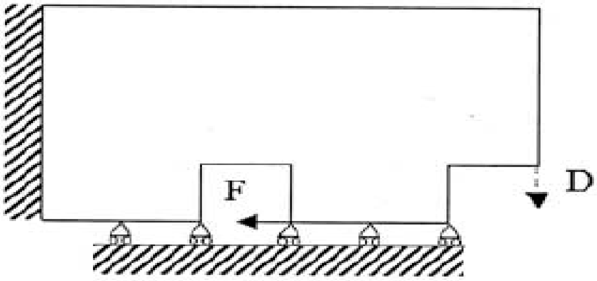

Fig. 4 Basic block structure

2) *Discretizing:* The device area into nodes that are connected by beam elements.

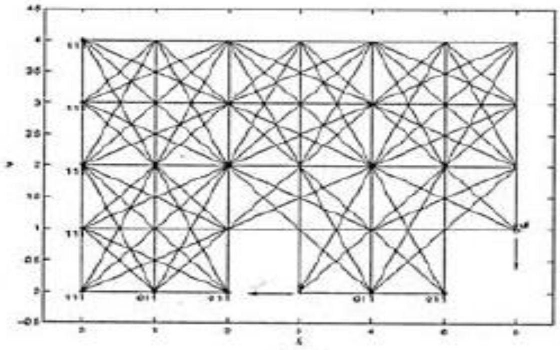

Fig. 5 Discretization of Device

3) *Synthesize:* The most optimum nodal design by using energy efficiency objective function

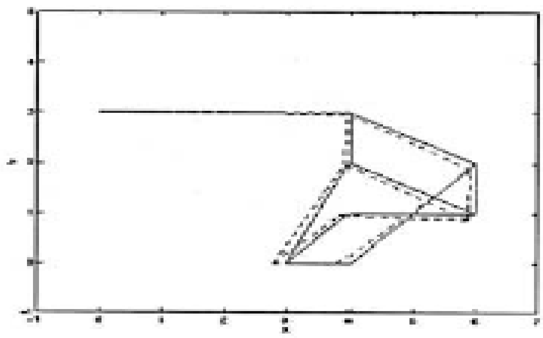

Fig. 6 Synthesisation of nodal Design

C. Size and shape optimization

Once we generate an optimal topology that meets the kinematic constraints, the next step is to optimize the size and shape of each of the beam elements such that they meet the desired performance characteristics. These performance characteristics can include weight, geometric and mechanical advantage, minimization of stress concentrations, and avoidance of buckling instabilities.

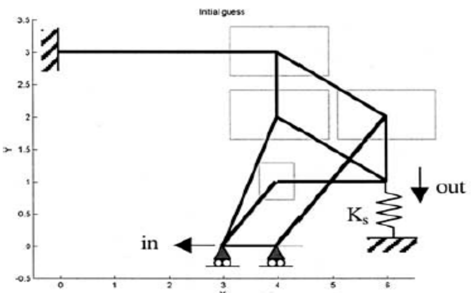

Fig. 7 Synthesized topology of mechanism

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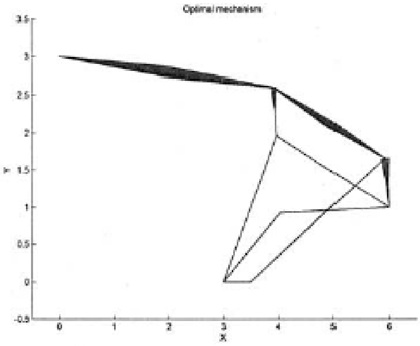

Fig. 8 The optimized geometry

D. Surgical Applications

1) Hand Gripper:

Need : Conventional Hand grippers are heavy and requires more force hence it is operation is tiresome

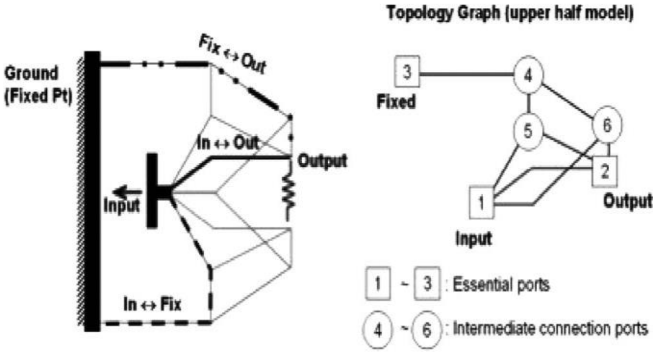

Fig. 9 Load and topology path

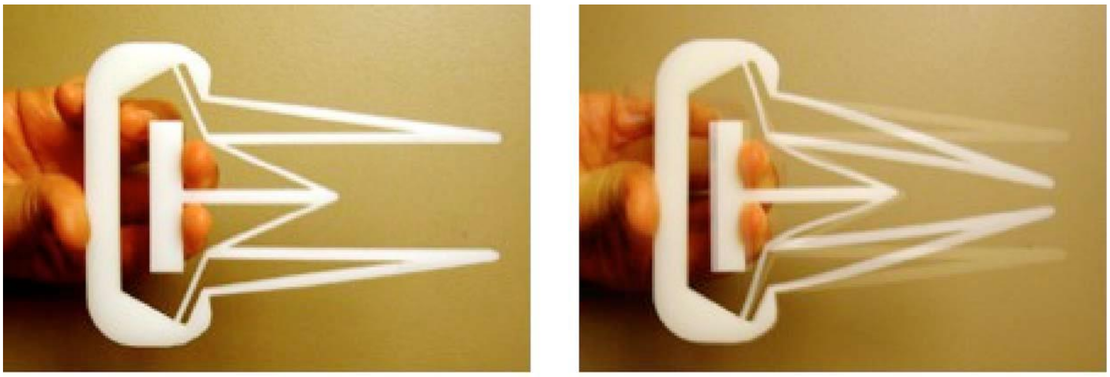

Fig. 10 Working of Hand Gripper

2) Kidney Manipulator:

Need: One of the limitations in telerobotic, laparoscopic surgeries is the lack of means to position and manipulate a solid organ, such as a kidney, liver, or pancreas. To perform such a task, an instrument must pass through an incision (small cut) of 1.5 cm diameter, and then expand to grasp and manipulate organs 5–15 times larger. Because telerobots are not yet equipped with such instruments to safely handle organs, manipulation is currently performed by an aide wielding two positioning rods for the duration of the surgery—a tiring and accident-prone process that can increase procedure time.

Objective**:** The objective is to develop a device that can safely and securely grasp a solid organ, integrated within one of the robotic arms of the system.

Closed position Kidney gripper shown with the compliant fingers contained within the 1.5 cm diameter tube

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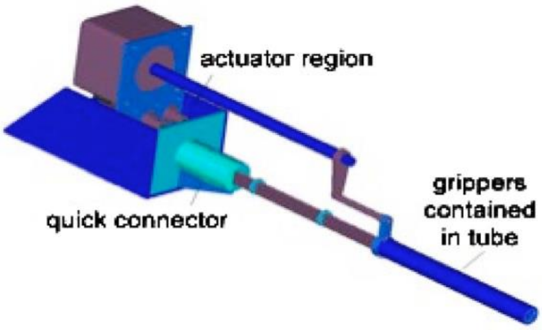

Fig. 11 Close position of gripper

Open position As the external tube is retracted, the fingers open to nominal position

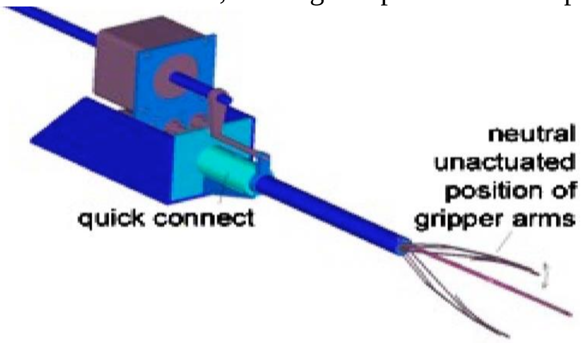

Fig. 12 open position of gripper

E. Future Research Scope

Recent research indicates that fully distributed compliant mechanisms enables embedded sensing. This can be done by embedding wiring within the mechanism to create a mutual inductance effect .The integration of such sensing with medical devices is a future research interest. Once implemented, it can provide an inexpensive and robust means of providing Haptic feedback to a surgeon. Such feedback can guide one as to how much force to apply to an organ or artery and thereby avoid any tissue damage.

IV. CONCLUSION

The paper highlights some of the benefits of engineered elasticity in the design of surgical instruments for laparoscopic and
robot-assisted surgery. The design methodology outlined in this paper is a general-purpose method developed for synthesis of
compliant mechanisms. A kidney manipulator was presented to demonstrate the advantages of monolithic, flexible tool:
joint-free design and inherent force feedback. The function of the gripper relies on its distributed compliance, which allows the gripper's fingers to be contained within a small-diameter tube thus enabling minimal invasion.

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