Tribology International ■ (■■■■) ■■■–■■■

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

# An active force controlled laparoscopic grasper by using a smart material actuation

İlker Murat Koç [a,*], Turgay Eray [a], Bilsay Sümer [b], Nurettin Çerçi [a]

[a] Department of Mechanical Engineering, Istanbul Technical University, Gumussuyu 34437, Beyoglu, Istanbul, Turkey
[b] Department of Mechanical Engineering, Hacettepe University, Beytepe 06800, Ankara, Turkey

ARTICLE INFO

*Article history:*
Received 5 October 2015
Accepted 2 March 2016

*Keywords:*
Laparoscopic grasper
Smart material actuation
Force control

ABSTRACT

The excessive grasper force may lead to irrevocable damage to the tissue in minimally invasive surgery. This study focuses on grasping mechanism of a laparoscopic surgery tool in order to control the grasping force. First, the dynamics of grasping mechanism of a conventional laparoscopic grasper is investigated using analytical and experimental methods. Then, a smart laparoscopic surgery tool is designed using the shape memory alloy wire with a bias spring. The grasper force is controlled through the actuator by different type of controllers and performance of the controllers are compared. Closed-loop dynamics of the grasper mechanism is achieved with 3.34% overshoot and zero steady state error.



## 1. Introduction

Over the past decade, laparoscopic surgery which is a minimally invasive surgery (MIS) method, has been given attention and widely utilized due to the advantages compared to the traditional surgery. Having a less pain after the surgery, less drug usage, lower risk of infection and hemorrhaging are some of the benefits of laparoscopic surgery to the patients [1–4]. In a MIS operation, the surgery takes place with special surgical instruments which hinders the ability of the human hand on the operation. The surgical instruments function as to provide vision of the surgical working area and to operate such as cutting, grasping, holding, squeezing tissue/organ of interest and suturing. These actions are operated within 3–15 mm width of small incisions which are broached on the abdominal wall of patient [1,2].

The surgical instruments and operations, considering the laparoscopic surgery itself, lead to significant disadvantages compared to standard open surgery [1–4]. The vision is obtained through incisions on the abdominal wall of patients where the operation is performed using the images from a video camera. Also, the degree of freedom and structure of the instruments limit the surgical working space. In addition, mechanical aspect of the instruments limits surgeon's capability to obtain diagnostic information. Surgeons while they are using the instruments, loose their capability to operate on tissue by touching it with the hands, where the tactile information such as stiffness of tissue, applied force on tissue etc. and diagnostic information are reduced [5]. It is generally accepted that the applied force to cut or suture is not needed to be considered during the operation, yet grasper force on tissue is an ongoing study [3,5–10].

Grasper force needs to be sufficient enough to hold and does not slip from the tissue of interest while operation takes place. Mostly slip and an excessive grasping force are the main sources of injury, that is, unnecessary damages take place to tissue [3,4,11,12], where the control of grasper force may be needed. The ideal grasping instrument should hold tissue without damaging it, however commonly used conventional laparoscopic graspers have an angular jaw, one or double sided, which leads to a non-uniform pressure on a tissue resulting a non-uniform grasper force. As a result, control of grasper force without damaging tissue needs attention. Obtaining the grasper force with new methods, such as calculating the grasper force from distributed pressure measurement [13] can lead to new control methods. Furthermore, while controlling the grasper force, friction force between a dummy finger and fabric gives inspiration to the friction force needed to hold an elastic tissue without slippage [14]. Additionally, in order to design and improve the surgical instrument to control grasper force while ensuring a safe grasping without slippage, it is important to understand the grasping mechanism of conventional laparoscopic graspers.

Conventional laparoscopic graspers have three parts: handle, middle shaft and jaw (commonly angular jaw). It is important to emphasize that the grasper force is transmitted through the shaft which acts as an actuator. Considering the mechanical aspects of the grasping instrument, the actuator plays a key role on the control

* Corresponding author.
*E-mail address:* kocilk@itu.edu.tr (İ.M. Koç).

http://dx.doi.org/10.1016/j.triboint.2016.03.001
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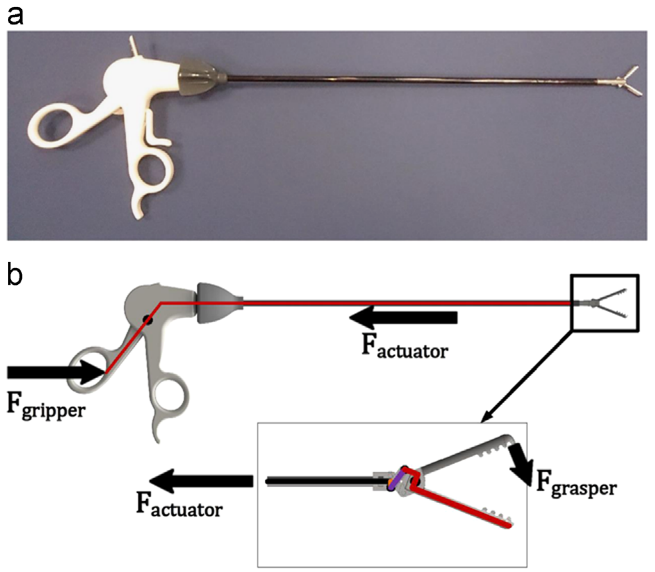


**Fig. 1.** Conventional laparoscopic grasper with an angular grasping mechanism (a). The grasping mechanism where the gripper force ($F_{gripper}$) is applied by surgeons, and the actuator force ($F_{actuator}$) is obtained in the middle shaft. As a result, the grasper force ($F_{grasper}$) is achieved within the grasper (b).

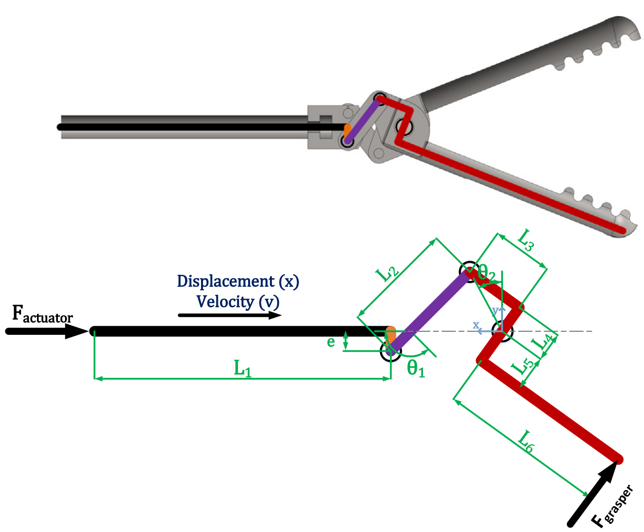


**Fig. 2.** Kinematic chain of the grasping mechanism, where $L_i$ and $e$ represent the length of respective links, $\theta_1$ is the angular displacement of the grasper, $x$ is the displacement and $v$ is the velocity of the middle shaft.

of grasper force. One way to control the grasper force is to design a suitable actuator to keep the grasper force under a safe level. Commonly used actuators are piezoelectric, direct current (dc) micro-motors and shape memory alloy (SMA) based actuators [3,15]. The smart actuators have their own advantages and drawbacks and mostly show different positive aspects, such as high stress can be achieved with piezoelectric and SMA actuators [16]. However, only SMA actuator provides higher strain values such that lower stroke of a SMA actuator can produce higher actuating forces [3,16]. Likewise, a dc micro-motor can provide preferable speed and large strain values, but they only allow low torque values [15]. Despite all the positive aspects of SMA materials, SMA is an actuator with a slow response time compared to other actuators. Especially, different response characteristic of the SMA actuator is obtained while the SMA actuator is heated or cooled [17]. However, an exceptional ability of SMA to remember and return to previous state, as well as bio-compatibility property [18,19], have led to

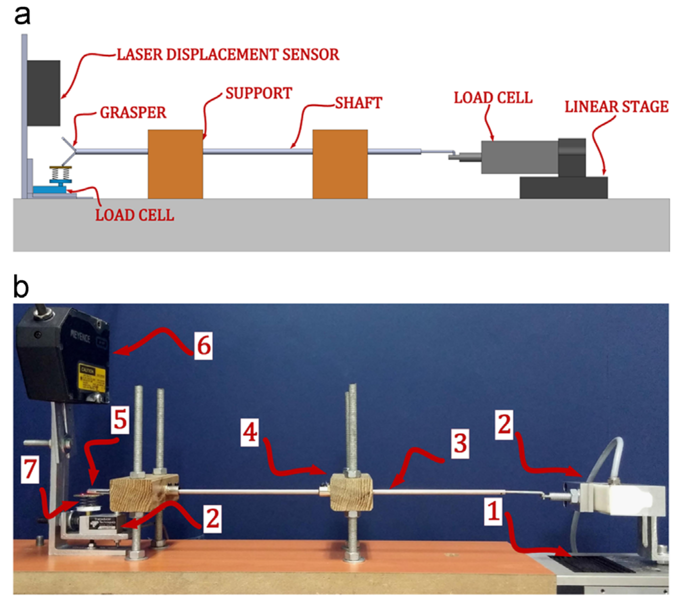


**Fig. 3.** Sketch of experimental set-up to obtain relationship between force and displacement of the grasping mechanism (a), Custom-built experimental setup, 1 – Linear motorized stage, 2 – Load cell, 3 – Shaft, 4 – Support, 5 – Grasper, 6 – Laser displacement sensor, 7 – Load cell (b).

usage of SMA actuators in medical operations, either in the form of a wire or a spring in order to control the force [3,17,20–22]. Here, it is important to point out that laparoscopic graspers to be designed have to meet the standard dimensions, if it is expected to be used in clinical operations.

In this study, the dynamics of a conventional laparoscopic grasper is investigated analytically and experimentally, where relationship between force and displacement for actuating force and resulting grasper force are obtained. A smart actuator which contains a bias spring and a SMA wire in order to meet the force/displacement requirements for the surgical operations is presented. The configuration is strictly designed to meet standard dimensions of the surgical instruments. Therefore, the designed laparoscopic grasper can be used in clinical operations. Grasper force is controlled with two different controllers; PID (proportional, integral, derivative) controller and sliding mode controller (SMC), where the structure of controllers as well as controller gain's effect are investigated. The analytical and experimental analysis are conducted to mimic the grasping of a tissue where the jaw can open or close. The paper goes in Section 2 with the characterization of conventional laparoscopic grasper. In Section 3, designing a smart actuation process is presented in detail. Results and discussion are covered in Section 4. Finally, conclusion is given in Section 5.

## 2. Conventional laparoscopic grasper

A conventional laparoscopic grasper is given in Fig. 1(a) which is used in the clinical operations. The forces in the grasping mechanism are shown in Fig. 1(b) where the grasping mechanism can be explained as follows:

1. The grasper contains a lever mechanism in the handle part where the surgeon applies the gripper force ($F_{gripper}$).
2. Actuator force ($F_{actuator}$) is obtained in the middle shaft of the grasper due to the gripper force.
3. The jaw of the grasper is opened and closed through the actuation; as a result, grasper force ($F_{grasper}$) is achieved.