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Feasibility of tracking laparoscopic instruments in a box trainer using a Leap Motion Controller

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ABSTRACT

Motion analysis is employed to assess minimally invasive surgical psychomotor skills in box trainers. Tracking of laparoscopic instruments requires sensor-based systems that can be expensive, limit movements and modify their ergonomic properties. We evaluate the feasibility of using Leap Motion as a cheap, unobtrusive alternative. Four experiments were performed to determine its precision while tracking a laparoscopic instrument inside and outside a box trainer. Static long and short term precision of the Leap Motion was <2.5 mm. Precision between 12 different positions within the box trainer was <0.7 mm for all measured distances between neighbors. Dynamic precision when moving the instrument for 200 mm ranged between 2 and 15 mm. Leap Motion presents acceptable precision values inside a box trainer. Improvements are still required (e.g.: multiple instruments' tracking). Once solved, a validation study should verify the usefulness of Leap Motion to objectively measure skills of novices and residents during training.

1. Introduction

Minimally invasive surgery (MIS) interventions are performed through small incisions in the patient's body, as opposed to conventional surgery [1]. MIS has become a standard procedural routine in many surgical subspecialties; including laparoscopic, gynecologic, nephritic and colorectal surgery [1]. In the case of laparoscopy, within the abdominal cavity a pneumoperitoneum is generated by infusing CO_2 gas, creating the working space for the surgeon. Long-shafted instruments are introduced through the incisions via special cannulas (trocars), and the patient's anatomy is recorded by means of an intra-corporeal endoscope and visualized on an external monitor [2].

Laparoscopic surgery is nowadays the preferred treatment method for a variety of procedures [3]. It is considered to be less painful and scarring to the patient, to reduce post-operative complications, decrease morbidity and mortality, and shorten hospital stays, thus reducing associated costs for clinical centers. However, it also introduces difficulties into the medical field, as it is technically demanding and requires different technical skills to those of open surgery [4].

Training and assessment of technical skills has become a major concern in MIS learning programs, especially

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considering the social demand for better-prepared professionals and for the decrease of medical errors [5]. Much effort is being put in the definition of structured learning programs, where practice with real patients in the operating room (OR) can be delayed until the resident can attest for a minimum level of psychomotor competence [5].

Several training methods have been developed to increase the skills of novices and residents in patient-free environments. One of the most employed is that of the laparoscopic box trainer. The box offers an enclosed space simulating the surgical scenario, with realistic dimensions, trocar access points and camera view. Real laparoscopic instruments are employed to perform simple tasks inside these low cost surgical simulators. These tasks are usually simple abstractions of reality, offering reproducible and repeatable routines with the sole purpose of training/assessing individual skills. It has been shown that these simulators do increase the skills of novices [6,7] and that those skills are transferable to the OR [8].

Finding the most adequate parameters to objectively evaluate basic laparoscopic skills is important. Studies have shown that objective measurements of laparoscopic skills include errors, time, and motion analysis of the laparoscopic instruments [4,9]. In particular, motion analysis has been extensively covered in the literature as a means of measuring performance differences between novices, residents and experts. Several authors have proposed scoring systems based on the movements of the laparoscopic instruments during basic training and assessment tasks, such as path length, average speed, or motion smoothness [4,10]. Reports have shown that in general these motion analysis metrics present good construct validity applied to technical skills' assessment, and nowadays their use is widely extended in commercial simulation systems [9,11]. Other authors have focused on the use of motion analysis to break down complex surgeries into a series of simplified tasks and maneuvers [12–15], combined with machine learning techniques such as hidden Markov models [12] or linear discriminant analysis [13] to automatically determine the steps in an intervention and assess skills in unstructured surgical tasks. The idea behind this approach is that in real surgical settings, the information provided by aggregated motion analysis metrics such as path length present a limited instructive value and do not describe tool motion sufficiently to provide formative feedback to trainees [14].

Motion analysis requires being able to track the movements of the laparoscopic instruments during performance of a task. Tracking technologies have traditionally relied on sensor-based systems, based on optical [16], electromagnetic [17] or mechanic [12] technologies. Nowadays, they are incorporated into different surgical systems for intra-operative navigation [18], robotic surgery [13] and surgical training (box trainers, virtual reality simulators) [9,11]. However, it can be argued that their use can modify the ergonomics and constrain movements of the instruments, altering the users' experience and performance. More recently, endoscopic video analysis is being explored as a means to provide tracking of instruments [19]. This alternative based on computer vision offers non-expensive and non-obtrusive tracking of laparoscopic instruments without the need of mounting sensors in them that may modify their ergonomics. However, the technology is still being perfected and is used mainly for research purposes, and is currently not commercially available.

Following the philosophy of providing affordable and unobtrusive computer vision-based alternatives, this study proposes the use of the Leap Motion Controller™ (Leap Motion, Inc., San Francisco, CA, USA) as a tracking device for motion analysis during laparoscopic training in a box trainer. The Leap Motion Controller is a small, accurate and affordable consumer device, which is able to detect and track objects without the need of affixing sensors to them [20].

The main objective of this work is to study the feasibility of tracking laparoscopic instruments using the Leap Motion Controller inside a box trainer, which, to the authors' knowledge, has never been studied before. A series of experiments are presented in order to determine its static and dynamic precision. This study is the first step in creating an application in which the motion of the tip of the instrument can be tracked during laparoscopic training by using the Leap Motion Controller.

2. Materials and methods

2.1. Laparoscopic instruments

Laparoscopic instruments are designed to allow access into the patient's body through small incisions. Typical design consists of an elongated, monochromatic (usually in black color) rigid shaft with a diameter of 5 mm, connecting a distal and a proximal end (Fig. 1). The distal end consists of a pair of metallic jaws that can be opened and closed, and which depending on their shape, allow the surgeons to perform actions such as dissection or grasping. The proximal end provides the instrument handle, which allows control of the jaws in four degrees of freedom (left/right pivoting, up/down pivoting, insertion/withdrawal, clockwise/anti-clockwise rotation) [21].

The surgical scenario (whether a real patient or a box trainer) is constrained by the view provided by the endoscope. In the case of the laparoscopic instruments, this means that only the distal end and part of the shaft will be visible on screen.

2.2. The Leap Motion Controller

The Leap Motion Controller uses two optical sensors and three infrared LEDs to detect objects within its field of view, which is located above the black surface of the controller [20]. It is able to recognize long thin objects, giving the location of their tip in Cartesian coordinates for every single frame.

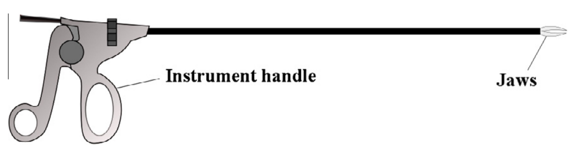

Fig. 1. Laparoscopic instrument model.