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A haptic pedal for surgery assistance

Iñaki Díaz, Jorge Juan Gil, Marcos Louredo*

CEIT and TECNUN, University of Navarra, Paseo Manuel Lardizábal 15, 20018 San Sebastián, Spain

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ABSTRACT

The research and development of mechatronic aids for surgery is a persistent challenge in the field of robotic surgery. This paper presents a new haptic pedal conceived to assist surgeons in the operating room by transmitting real-time surgical information through the foot. An effective human–robot interaction system for medical practice must exchange appropriate information with the operator as quickly and accurately as possible. Moreover, information must flow through the appropriate sensory modalities for a natural and simple interaction. However, users of current robotic systems might experience cognitive overload and be increasingly overwhelmed by data streams from multiple modalities. A new haptic channel is thus explored to complement and improve existing systems. A preliminary set of experiments has been carried out to evaluate the performance of the proposed system in a virtual surgical drilling task. The results of the experiments show the effectiveness of the haptic pedal in providing surgical information through the foot.

1. Introduction

During a surgical procedure surgeons require a great amount of information in order to operate the patients as effectively as possible. This information is quite varied and may range from meaningful patient signs (e.g. heart rate) to X-ray images of the target area. Today's operating rooms are usually equipped with a wide range of tools that supply surgeons with this information, mainly by means of visual and sound feedback cues. However, sometimes this information overloads the surgeon's visual and auditory senses and as a result such information is neither efficient nor comfortable for the surgeon [1].

In an effort to provide information to surgeons more efficiently and through other channels, this paper analyses the human sense of touch as an additional communication channel. During a surgical procedure, the surgeons already process information through their hands, that is, they receive tactile feedback, since they usually operate with hand-manipulated surgical instruments. However, the sense of touch is not explicitly used as a communication channel in order to provide surgeons with additional information (e.g. patient status information). This is mainly due to the high mechanical complexity of such communication channels, as well as the obvious danger of sending force and tactile stimuli to the hands of the surgeon while he is operating. Nevertheless, it is known that reaction times (RT) for tactile stimuli are much lower than for visual stimuli [2,3] and thus they are more appropriate for communicating critical warning signals.

In an attempt to overcome the current limitations to using the human haptic sensorial system as a communication channel in the operating room, this paper investigates whether the foot is a valid receptor/emitter. One of the properties of the human sense of touch is that it can be sensed all over the body, unlike the other senses, which are located in specific parts of the body. Therefore, even if humans are accustomed to associating the sense of touch with our hands, tactile and force stimuli can also be sensed in other parts of the body. Moreover, in some surgical procedures, for example, surgeons and dentists already use foot pedals to command certain surgical instruments with their foot. The major advantage of using these systems is that the surgeons have direct control

* *Corresponding author*. Tel.: +34 943212800; fax: +34 943213076.
E-mail addresses: idiaz@ceit.es (I. Díaz), jjgil@ceit.es (J.J. Gil), mlouredo@ceit.es (M. Louredo).
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over many parameters of the surgical instruments, while their hands free for the main surgical procedure.

This present work proposes a specially designed haptic foot pedal in order to provide surgeons with information through the sense of touch. Haptic devices allow users to interact with a certain environment, either remote or virtual, through the sense of touch [4]. In recent years these interfaces have been successfully integrated into a wide range of fields such as engineering [5] and surgery [6,7].

The primary goal of the present study is to examine the effectiveness of perceiving surgical information through the foot. Therefore, a user-study has been carried out to validate the benefits of sending tactile stimuli to the surgeon through the haptic pedal. The experiments consist of sending tactile warning cues to the user during a simulated drilling process to determine if such warnings can improve the end-point in the drilling task. The proposed scenario tries to emulate surgical drilling procedures, where it is very important to avoid drilling deeper than necessary in order to minimize the damage caused to soft tissues [8,9].

The paper is organized as follows: Section 2 introduces the most common robot-surgeon interactions, and Section 3 describes in detail the proposed haptic communication modality through the foot. Section 4 reviews existing foot pedals while Section 5 presents the proposed haptic pedal. Section 6 describes the experiments carried out to analyse the efficiency of commanding haptic stimuli through the foot. Finally, conclusions are presented in Section 7.

2. Surgeon–robot interaction

Technological advances over recent decades have opened up very different ways of operating and working in operating rooms. The same surgery can be performed in very different ways depending on the technology applied [10]. For example, open procedures have been replaced by minimally invasive surgeries whenever possible [11]. Thanks to the invention of laparoscopes for example, operations in the abdomen are performed through small incisions which reduces haemorrhaging and shortens recovery times, among many other advantages. However, the use of a laparoscope means that the surgeon loses his direct three-dimensional (3D) view of the operation site and has to manage with a 2D video image instead. In addition to affecting their vision, surgeons must also use tools to interact with tissue rather than manipulating it directly with their hands, which causes them to lose very valuable haptic and tactile information.

Robotic technology has opened an additional operating experience: telesurgery, i.e. the ability to operate remotely [12]. The technology tries to solve some drawbacks of the laparoscopic procedure (e.g. it provides unrestricted movements and precise control of instruments inside the patient and high resolution 3D images) by incorporating appropriate robotic tools and also allowing the operation to be controlled remotely [13,14]. Despite these improvements the complex problem of returning the natural touch and feel of the operation site to the surgeons has not been completely solved by haptic feedback.

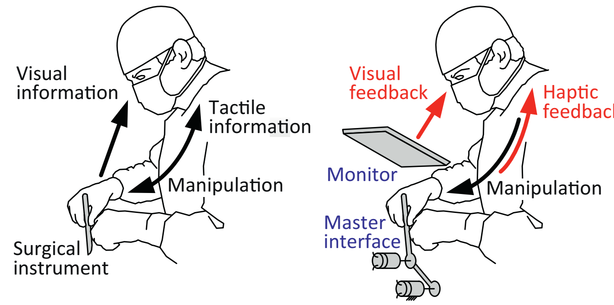

Fig. 1 – Sensory information in unsupported and open procedures (left) and robotic operations (right).

A different robotic aid in surgery is the collaborative robot, known as COBOT [15,16]. These systems are complex machines which work hand in hand with human being: in other words, they support and relieve the human operator. Unlike common master–slave robotic configurations used in telesurgery systems, COBOTs come into direct contact with surgeons. Some portions of a surgical task are performed autonomously under the complete control of a surgeon, and other portions are performed manually by the surgeon.

Each surgeon–robot system has its own advantages and drawbacks, but all of them affect the natural processing of visual and tactile information compared to the traditional unsupported and open procedure. The different solutions present sensory information in very different ways and thus have different implications on the surgeons' sensory-motor system (Fig. 1).

Much work is currently under way to provide more effective sensing technologies and additional displaying devices to these systems, e.g. the development of 3D cameras for the visual channel [17]. Certainly, the most demanding scheme is telesurgery, where the system must gather the maximum information about the remote site and display this information as accurately as possible to the surgeon, enabling him to operate remotely

In most cases, the success of these complex systems does not only depend on the related technological solutions for displaying all the information, but also on how to combine such information and through which sensory channels the information should be delivered in order to be effective. Several universal design concepts for combining visual, audio and haptic devices are already well known in the literature. For example, there are those that are related to the issue of sensory overload, which is a condition where one or more of the senses is strained and it becomes difficult to focus on the task at hand [18]. Humans have a limited capacity to receive, hold and cognitively process information, which limits the design of sensory substitution or sensory augmentation approaches [19]. The cross-relations and the coupling between the sensory and the motoric components are other very important issues.

In an effort to relieve the overloaded vision and audio sensory channels, this work proposes using the human foot as an alternative, and so far unexploited, communication channel. The proposed solution is valid both for robotic and non-robotic surgical devices.