Spatially distributed stiffness rendering system for handsfree palpation

Sergio Portolés Bert Willaert, Emmanuel Vander Poorten and Dominiek Reynaerts
Dept. of Mechanical Engineering, KU Leuven, 3001 Heverlee, Belgium
Email: sergio.portolesdiez at mech.kuleuven.be

***Abstract*—Robotic surgery is a relatively young field of research. The effectiveness of surgical robotic devices remains subject of debate. While the ergonomy of the employed interfaces is considered a strong point, the content and quality of the information that they feed back and present to its operator be it a surgeon or a trainee is still limited. Therefore a lot of research is being conducted in search for intuitive and effective interfaces. In this abstract a novel haptic interface for handsfree palpation is presented. The interface follows the principle of an encountered-type robot replicating more naturally the actual palpation procedure. The concept of this new development is presented. The control method to render spatially distributed kinaesthetic information is explained next. Experimental results show a proof-of-principle towards a more natural palpation.**

I. Introduction

Robotic surgery is an emerging technology stirring up lots of animosity into modern medicine. Robots can be seen performing tasks in orthopedic surgery, neurosurgery, gynecologic surgery, urology or cardiothoracic surgery. Some of the more popular platforms are e.g. the Magellan Robotic system of Hansen Medical, DLR's MiroSurge [1] or da Vinci® of Intuitive Surgical. While the the number of procedures suited for robotic assistance remains low, this number is increasing and robotic solutions are drawing more and more the attention of surgeons. One of the possibly most cited drawbacks of robotic surgery is the lack of haptic feedback. Haptic feedback is very much present in manual laparoscopic interventions [2] and its presence is shown to greatly improve the perfomance and reduce the learning curve [3], [4]. Haptic features can help to prevent collisions between instruments [5], but also for palpation, to diagnose and localize tissues, damaged cells or tumors; even if other methods exist (CT or USG), haptic feedbak remains essential [6].

In this abstract we present in section II the *haptic screen*, a novel haptic device that was developed to allow more natural haptic-feedback-enhanced palpation. A brief word about the control of this device is described in section III. Some first results are reported in section IV.

II. Design of a haptic screen

A novel approach to recreate natural palpation according to the encountered-type display principle [7]–[10] is presented here.

The haptic screen, a large area haptic display has following features: *a)* display renders spring-damping impedance *b)* encountered-type interaction allowing hands-free manipulation and *c)* haptics feedback derived form spring-damping virtual reality simulation.

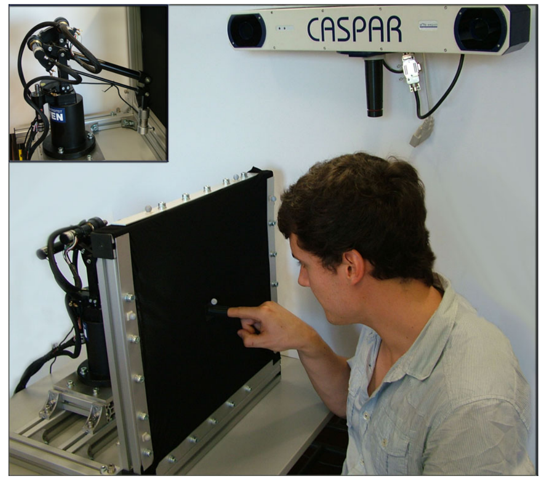

Fig. 1. Overview of the whole system

A. System overview and principle

The haptic screen consists of a membrane placed in front of the user representing a palpation plane with whom the user can interact (Figure 1). Additionally, the robotic system is equipped with a vision system that measures the relative position between the user's hand and the haptic surface. The hand pose is used to command the motion of an encountering haptic device behind the screen. An in-house developed 3 d.o.f. haptic device [11] was used for this purpose. While sitting in front of the haptic screen and moving his/her finger this device mirrors the hand motions. When the hand comes into contact with the screen, kinaestic feedback is rendered to the user, replicating natural palpation. The workflow of a palpation task can thus be divided into next steps:

1) a user takes place in front of the screen,
2) extends the arm approaching the screen, a.k.a. approaching stage.
3) the robot mirroring the user, waits at the surface.
4) user's finger enters into contact w. haptic surface.
5) applying pressure at the surface.
6) robot presents impedance mimicking virtual or remote tissue corresponding to that contact location / finger position.
7) user removes disengages.
8) new palpation cycle can start.

B. System components

To turn the robotic system into a handsfree palpation display, a tracking system and a tensioned membrane are employed. Below a brief explanation of these elements.

1) Tracking system: A tracking system is required to position and encounter the user's motion at the appropriate instant in time and the correct location. A Polaris® tracker from NDI was selected for this purpose. The tracking system reads in the position of reflective markers normally placed somewhere in the surgical theater. Here, a single marker was attached to the distal phalanx of the finger. For easy registration of the finger with respect to the haptic screen ${}^{marker}_{screen}\boldsymbol{p}$ additional markers were fixed upon the frame of the haptic screen.

2) Membrane as haptic surface: The haptic surface is approximated as a plane that represents the surface of the patient's organ to be examined. Here, a polyethylene fabric was selected and mechanically fixed to a vertical rame between user and robot. The membrane smoothens out the interaction creating the feeling of a continuous contact. It further adds to the overall safety. The membrane does introduce an additional impedance during in-contact motion, but this is assumed to be negligible within the range of the impedances rendered by the haptic device, as: $Z_{membrane} \ll Z_{HRI}, Z_{control}$.

III. Control for haptic rendering

A tracking controller and an impedance controller are used for respectively approaching phase and in-contact motion. The latter is described below in some detail.

A. Stiffness control

Figure2 shows an impedance controller with inner proportional force feedback loop, analysed in detail in [12], that was used to render a desired desired impedance Z_d to the user.

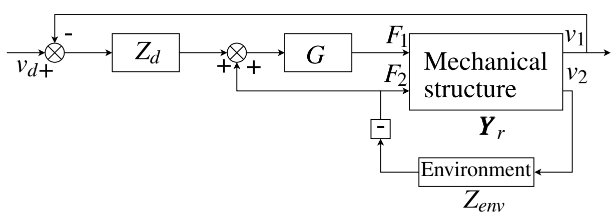

Fig. 2. Schema of the impedance controller

B. Kinaesthetic map

The desired impedance Z_d is selected as function of the position of the finger $Z_d = f({}^{marker}_{screen}\boldsymbol{p})$. The result is a distributed impedance map corresponding to the distributed impedance of an organ. High stiffness values are e.g. used to simulate nodules hidden underneath the surface.

IV. Experiments

Two tests were conducted to verify the device performance.

A. Map exploration

A map exploration experiment replicated a palpation procedure similar to the one applied during normal operation. Two nodules were positioned along a horizontal line of the haptic surface. A user follows the line applying pressure along it. The forces at the end-effector are recorded for any position of the finger. Fig. 3 shows the forces of the transducer, positions of the finger and desired stiffness in w_x direction. The graph shows nicely how forces increase when the desired stiffness grows and that often the amount of indentation reduces in such cases. Figure 4 shows the relation between force and position, the perceived stiffness, plotted against the desired stiffness. A certain mismatch at high values of stiffness can be observed, while low stiffnesses are rendered fairly well.

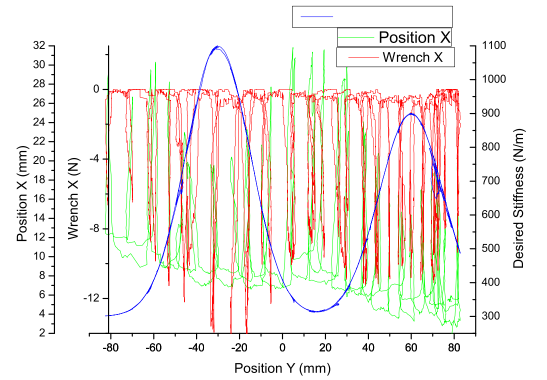

Fig. 3. Finger position, end-effector forces and desired stiffness are compared along the scanning line (z=0)

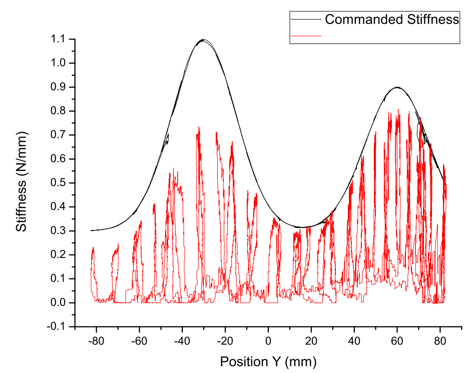

Fig. 4. Measured perceived stiffness is compared with the desired stiffness commanded by the kinaesthetic map

B. Perceptual tests

A user test was performed in the following conditions. Six right-handed users with ages comprised between 26 – 35 years old were asked to palpate the haptic surface. The users were told to find 3 hard nodules on 3 different maps using as much the time as they needed. A training phase preceded once for every user to get used to the system. The workflow was explained and two training maps were shown.

Once a user finds the centre of a nodule he/she is asked to hold the position and the examiner records it. After three guesses, the experiment finishes and the next map is loaded.

Figure 5 shows the locations of the centre of the nodules as indicated by the users. The kinaesthetic map is also depicted to see the accuracy of the user guesses. There is a good correspondence between indicated and rendered nodule locations. It should be noted that some users identified the same location twice (nodules with more than 6 marks).

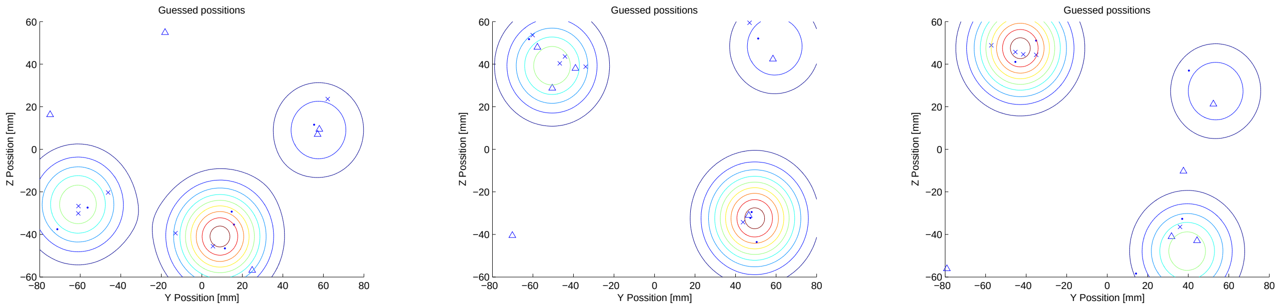

Fig. 5. Estimations of the position of the stiffness peaks made by the users. The level lines indicate the geometric place for iso-stiffness values.

V. Conclusions

In this abstract the proof of concept of a novel haptic interface to render large areas of kinaesthetic information for hands-free operation in encountered-type basis is presented. The proposed system consists of an interfacing membrane, a tracking sytem and an encountering mechanism. By releaving the need of continuously gripping the display, the minimum achievable impedance can go down to $Z_0 = 0$ increasing the Z-width of the device.

Experimental results show that stiffness can be represented with an encountered-type haptic interface. Nevertheless, there is still some mismatch on the fidelity of rigid walls as shown in the map exploration test. Other problems associated with such interface are the the lack of robustness of the current implementation and a low update rate of the tracking system. Some work on these points is planned for the future.

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