Palpation Strategies for Artificial Soft Tissue Examination

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***Abstract*—This paper presents studies developed to understand the need of the specific behavioral strategies during artificial tactile examination of soft tissues for robot-assisted minimally invasive surgery. Conventional manual palpation techniques are studied to understand the desired patterns that should be applied using intra-operative tactile probes. In addition the tele-manipulation studies are carried out. Our results demonstrate the importance of application of specific palpation behavior during artificial tactile examination.**

Keywords— Robot-Assisted Minimally Invasive Surgery, Medical Robotics, Palpation, Soft Tissue, Tele-manipulation

I. Introduction

Robot-assisted Minimally Invasive Surgery (RMIS) is an advanced medical procedure that allows reducing the recovery time and complications for patients during various types of surgical procedures [1]. The appearance of robotic surgery induced the rapid development of associated technologies, such as advanced interfaces and smart instruments [2], [3].

RMIS is performed via small trocar ports that do not allow surgeon to palpate organs, to understand the location of tumor, for instance. The representation of the surgical environment is typically represented with the help of high-quality spatial visualization (e.g. Da Vinci Surgical system), which cannot give a complete representation of soft tissue mechanical structure, such as stiffness. Therefore, a number of miniature tactile devices are developed to enable tele-manipulated palpation of the organs during surgical procedure [4–6]. Nevertheless, surgical tactile devices are not broadly used for RMIS yet. This happens mainly because the devices developed for surgical applications are required to be accurate and well tested. Consequently, the result of tactile examination should be efficient and reliable. However, non-linear mechanical properties of soft tissues and additional factors, such as the mobility of internal organs and the flows of body liquids lead to the complexity and uncertainty of the environment. Thus, the results of tactile examination can be subject to high variability of results.

In our studies, we propose that the result of tactile examination depends not only on the technical parameters of a device, but also on the environmental conditions. In order to take into account the above-mentioned factors and to improve the accuracy of the tactile examination, specific patterns can be used [7–10], similarly as it is done for the manual palpation. Therefore, we study the way people use manual palpation to detect hard nodules embedded in a softer material, which represents soft tissue. The aim of such studies is to understand salient features of manual palpation, as well as to understand the search patterns.

The second issue, concerning soft tissue tactile property measurement is the translation of the haptic feedback to the user. For this purpose, a number of tele-manipulation systems have been developed [11–13]. In this work, we use the system, presented in [14] to study the palpation behavior during tele-manipulated palpation of soft tissue. Thus, it is needed to understand, whether the application of the specific search pattern can enhance the performance of the tactile examination and to increase the detection rate of hard nodules.

II. Manual Palpation Trajecotry Pattern

A. Studies on Manual Palpation

For the studies of manual palpation, twenty participants have been recruited [15]. Ten out of them had prior surgical or manual palpation experience.

During experimental evaluation of manual palpation, subjects were asked to palpate an artificial organ with embedded tumours. The relation of stiffness between soft tissue and abnormity is created according to typical conditions of cancer disease, as the abnormality is typically stiffer [16]. A silicone block with embedded hard nodules is used in our user study. To fabricate this silicone block, silicone gel (RTV6166, ratio of 4:6, viscosity of 900 mPa·s) was used. The hard nodules, of different diameters (6, 8 and 10 mm), were embedded at different depths from the surface of the silicone material. To create the nodules, a hard silicone compound (RTV615, ratio of 10:1, 4000 mPa·s viscosity) was used.

The experimental setup is shown in Fig.1. The trajectory of palpation was measured. The applied forces are recorded with six degree-of-freedom force/torque sensor MINI 40 (ATI Industrial Automation, normal force resolution 0.01 N). A Microsoft Kinect sensor (sample rate 30 fps, 640 × 480 pixel resolution) is used to track the spatial position of the hand using Microsoft Visual C++ OpenCV package. The position accuracy for the Kinect sensor was obtained experimentally for an average palpation velocity, and is 1-2 mm.

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To understand the strategies used by subjects to get information about the properties of the embedded nodule, we examined the experiments of movement of free one-finger palpation.

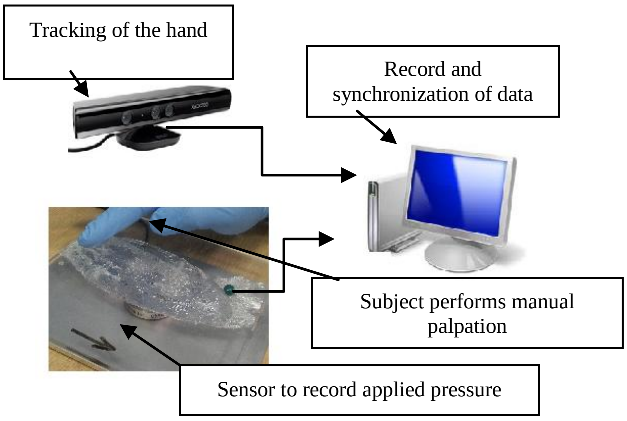

Figure 1. Schematic representation of the experimental setup

B. *Result*

Fig. 2 demonstrates the distribution of palpation velocity and applied finger pressure over the trajectory over a phantom organ. Both experts and novices have indicated the use of specially applied behavioural pattern to enhance the detection of hard nodules. The trajectories almost cover the entire surface of the artificial organ; circular movements can be observed in the vicinity of hard nodules.

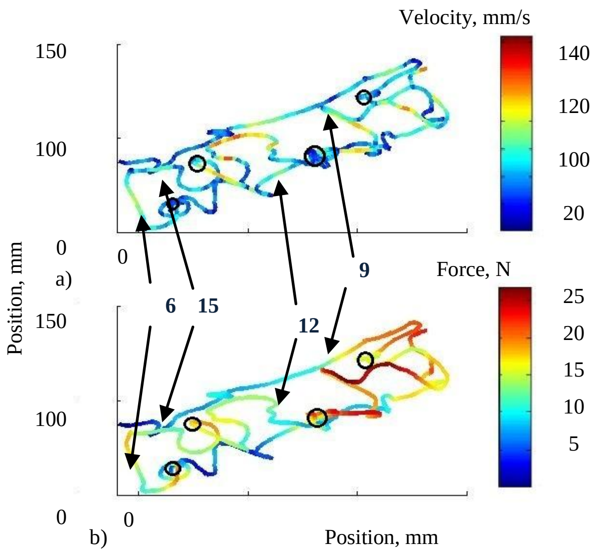

Figure 2. Representative example of palpation path over a phantom tissue with four embedded nodules (diameters in mm marked with arrows): a) modulation of velocity magnitude, b) modulation of applied finger pressure.

III. Studies on Palpation using Tele-manipulation

A. *Tele-manipulation Setup and Test Protocol*

The purpose of our studies is the application of artificial tactile sensors during RMIS. Therefore, as a next step, the tele-manipulation experiments were performed. To study the use of manual palpation strategies, which have been addressed in section II, during RMIS, the experimental tele-manipulation platform, shown in Fig. 3 is used. Soft tissue phantom is examined remotely with a tactile probe, and haptic and visual information about the stiffness is fed back to the human subject. This setup enables the possibility to study various strategies of soft tissue remote palpation or probing.

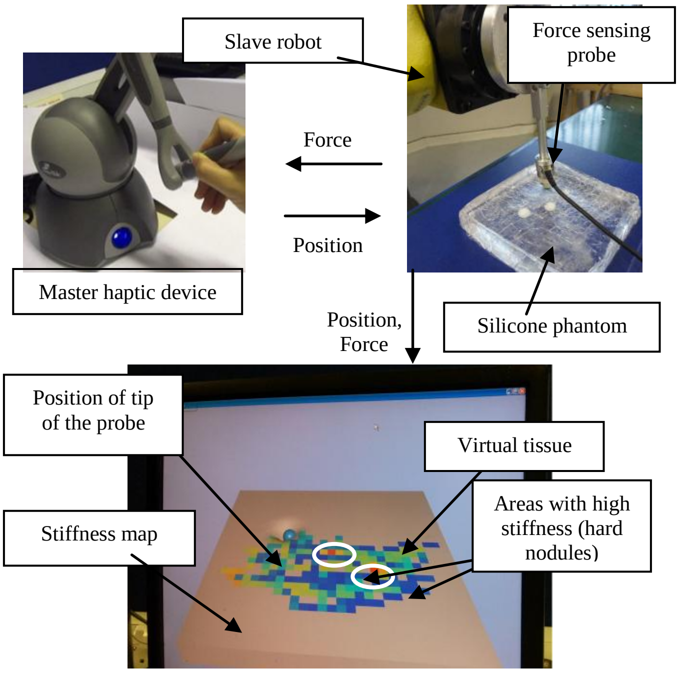

Figure 3. Tele-manipulation setup

B. *Random palpation trajectory vs. manual palpation trajectory pattern*

Subjects were asked to perform two tests [17]. Firstly, users were asked to palpate the artificial use random palpation behavior. Then, to understand the fidelity of manual palpation pattern during remote palpation, participants were asked to apply consequent scanning of the silicone combined with circular movements over possible locations of hard nodules [18]. This pattern is typically used for clinical breast examination.

A master haptic device (Phantom Omni, Sensable Technologies) is used to operate the probe, with 8 mm spherical indentation tip. A force and torque sensor NANO17 (ATI technologies) measures normal and tangential forces from the lubricated surface of the silicone phantom. A slave robot arm follows the defined trajectory, rolling the force-sensing probe over the phantom tissue. The accuracy of the position tracking for the tele-manipulation is 0.2 mm. The average delay for the position tracking is 0.25 sec with standard deviation of 0.04 sec.

A virtual tissue representation is displayed on a computer monitor. The position of the probe is displayed in the virtual environment in real time. The pointer (cursor) of the virtual model is moving according to the user-defined trajectory and reflects the position of the probe in real-time. The deformation of the tissue is shown on the virtual model according to the indentation depth. Stiffness distribution color map is created using force and indentation depth data, and areas of high

stiffness are shown with the high intensity color. The RGB color value reflects the value of stiffness (increasing from dark blue to red). The colors of the stiffness map are updating in realtime with regard to an updated range of magnitude of stiffness.

Subjects receive visual and haptic feedback in realtime during tele-manipulation. Haptic feedback is exerted via a haptic device (the master robot) in three dimensions. Tree-dimensional force feedback enables the display of not only normal force but also dragging forces (tangential direction).

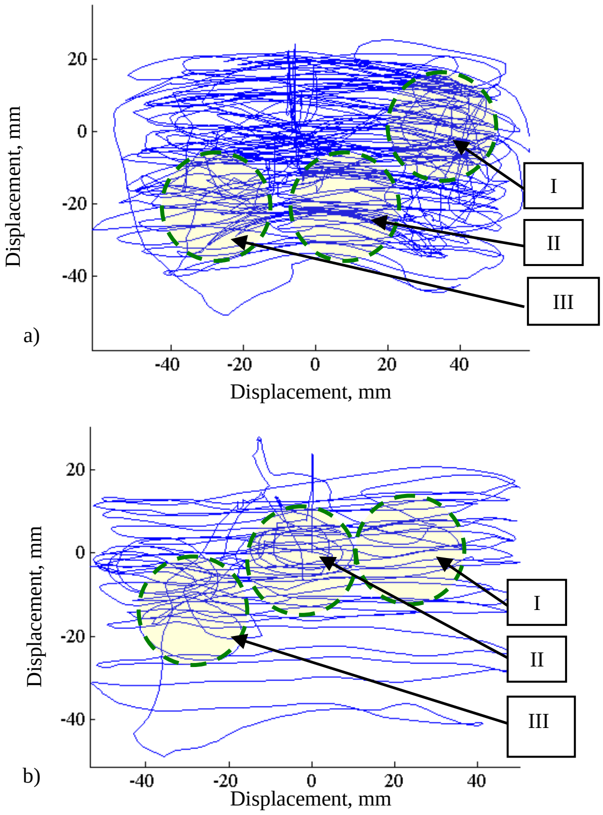

Figure 4. Trajectory of remote palpation for: a) unrestricted and unstructured user-defined movements – Test1, and b) pre-defined pattern – Test 2; the orientation of the silicone phantoms is different for two tests, the locations of hard nodules – I, II, III

A. *Results*

The trajectory of the movement for two trials using tele-manipulation was recorded and evaluated. Fig. 4 shows the sample trajectories of one subject performing two tests.

The results show, that 30% of subjects have used some palpation pattern during first trial (subjects were defining the palpation trajectory), such as intensive circular patterns in the vicinity of a hard nodule. For the second test, subjects were asked to apply the pre-defined pattern. The analysis of trajectory shows that all subjects were successful in that task, and all have applied the circular pattern for the possible locations of nodules along with the sequential scanning of the silicone phantom.

To evaluate the effectiveness of the second palpation test, the detection rate of hard nodules was evaluated. The overall result shows that the second test was more productive across all subjects, see Table I. Moreover, small nodules were detected more often for the second tests. Three-way analysis of variance showed the influence of trajectory pattern on the detection rate of hard nodules ($p < 0.001$). In addition, the time spent for the second test was significantly less ($p < 0.001$). All subjects have indicated that the use of special pattern improves the efficiency of examination.

TABLE I. DETECTION OF EMBEDDED NODULES

Nodule, diameter	**Detection rate for all tests, %**	
	Undefined pattern (Test 1)	***Defined pattern (Test 2)***
A, 10 mm	80%	100%
B, 8 mm	90%	90%
C, 6 mm	50%	80%
All together	73%	90%

IV. CONCLUSIONS

Our results have demonstrated the importance of specific behavioral pattern during remote soft tissue palpation. Therefore, the application and usage of artificial tactile devices can be improved. We propose that in order to get a better understanding about the optimal examination strategy, the interaction dynamics between soft tissue and a device should be studied. One needs to take into account not only the trajectory of examination, as it is shown here, but also the modulation of force and velocity of palpation. In addition, the unpublished work demonstrates the significance of the examination material. Therefore, we believe, that in order to introduce artificial remote palpation, there is a need for the development of behavioral control policies and algorithms.

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