Pseudo-Haptic Feedback for Tissue Stiffness Simulation

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***Abstract*—This paper introduces a low-cost simulation technique for soft tissue stiffness and hard inclusions. Although without expensive haptic interfaces users receive only visual feedback (pseudo-haptics) when maneuvering an indenter avatar over the surface of a virtual soft tissue by means of an input device – a pressure-sensitive touchpad or tablet, the alterations to the indenter avatar behavior induced by the method creates the experience of actual interaction with a hard inclusion in the user's mind. The proposed method is experimentally evaluated for hard inclusions identification. It proves that this pseudo-haptic feedback method can be used to express haptic information in palpation.**

***Keywords*—haptic feedback; palpation; pseudo-haptic feedback; tumor identification**

I. INTRODUCTION

Tissue stiffness distribution within an organ can be perceived through the application of appropriate forces to an organ and the observation of the resulting indentation. Simulating the function of haptic sensations resulting from palpations is beneficial for tissue abnormality identification in medical training. 3D haptic devices are commonly used for palpation simulation [1]. One drawback for those devices is that the costs are relatively high. Pseudo-haptic feedback creates an illusion of haptic feedback by visual display [2]. Haptic devices are not needed when pseudo-haptic feedback is applied. In our previous work, the pseudo-haptic feedback technique is applied to simulate soft tissue stiffness using a computer mouse [3]. Lateral reacting force of sliding behavior and normal reacting force of indenting behavior are simulated separately. In this paper, a pressure-sensitive touchpad is used as a motion input device that lateral force and normal force are simulated simultaneously.

II. METHODOLOGY

The relationship between the input device movement and the movement of the slave indenter avatar is introduced. The avatar display ratio is the relationship between the indenter avatar displacement distance (*d*) and the input device displacement distance (*D*) ($R=d/D$). Therefore, the movement speed of the indenter avatar can be reduced by changing the avatar display ratio when it is approaching a hard inclusion. The user can experience a corresponding resistance when the speed of indenter avatar is slower. If the user moves the input device towards a relative hard area on a certain distance (D), the indenter avatar display ratio will be modified to be smaller than the original ratio ($R_m<R_o$, R_m is the modified ratio and R_o is the original ratio), thus the modified avatar displacement distance dm will be smaller than the original indenter avatar displacement distance do ($d_m=R_m D$, $d_o=R_o D$), and a resistance to motion will be experienced compared with when the original indenter avatar display ratio is applied. Thus, virtual forces (*VF*) are perceived through visual perception along the movement direction. Rather than applied to the user's finger, virtual forces are directly exerted on the indenter avatar. In order to achieve position correspondence, the indenter avatar will move faster when moving away from the hard area until the position correspondence is reached. The frame diagram of the pseudo-haptic soft tissue stiffness simulation using a pressure-sensitive touchpad motion input device is shown in Fig. 1.

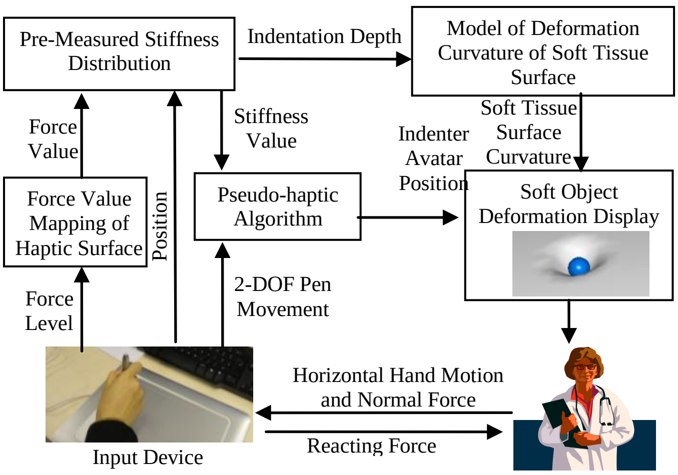

Fig. 1. The block scheme of the pseudo-haptic soft tissue stiffness simulation using a pressure-sensitive touchpad motion input device.

In this pseudo-haptic soft tissue stiffness simulation, deformation of the virtual soft tissue during indentation is displayed in real time using a geometrical deformable soft tissue model, which was established based on predefined finite element modeling considering the influence of the indenter diameter. The detail of this model is presented in [4]. If a node of the mesh is pressed by the indenter, the normal vertex of this node is redefined according to the depth of the indenter. At the

same time, the normal vertices of other nodes nearby on the mesh are affected by the indentation and are adapted according to the geometrical model to display the tissue displacement. If the indentation depth increases, the number of the affected nodes increases.

The stiffness distributions used in the simulation came from two soft silicone blocks with hard nodules embedded. The stiffness distribution of the two silicone blocks were obtained using a force-sensitive rolling probe, which can be attached to a rigid tool to scan the surface of a soft tissue to obtain its force distribution by concurrently measuring the tool-soft tissue interaction dynamics as it rolls over the surface of the soft tissue. The force distribution matrix can show the stiffness distribution of the soft tissue at a given indentation depth [5]. If the indentation depth is zero, the coordinates recorded would be the contour of the soft tissue. The stiffness distribution used in the pseudo-haptic soft tissue stiffness simulation comes from a silicone block. This silicone block was $120 \times 120 \times 25$ mm^3 with three spherical nodules embedded inside.

In order to validate the pseudo-haptic soft tissue stiffness simulation using a force-sensitive haptic surface, a user study was conducted. Twenty participants (all have engineering background, one subject is a surgeon, others had no palpation experience), participated in the empirical study. First, participants were also asked to do a practice run with known tumor locations. Then, participants were asked to manipulate the input device to palpate the virtual soft tissue and observe the change of the ratio between the indenter avatar displacement distance and the input device displacement distance. When they found hard inclusions, they recorded the positions of them. Time consumed was also recorded.

III. Results and Discussion

The smallest tumor C has a low detection rate which is 15%. The detection rate of nodule B is the highest (75%), followed by nodule A (65%); it is interesting to note that nodule B has a higher detection rate despite being smaller than nodule A. It implies that this method is more suitable for detecting middle sized nodules. Three participants (15%) detected all nodules while the same rate of participants detected no nodules at all. Eleven participants (55%) detected more than two tumors correctly. The detection rates for the three nodules are 65%, 75% and 15%. Total nodule identification (51.7%, SD= 31%) indicates that there is a high inter-individual variability of the performance. The average time is 248.9s.

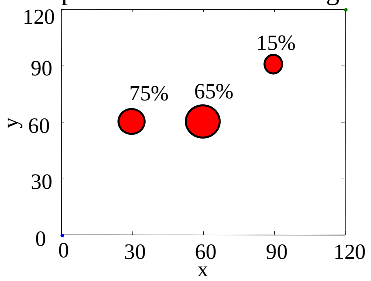

Fig. 2. Nodule identification results of pseudo-haptic feedback using touchpad as input device

This pseudo-haptic palpation simulation method produces visual and haptic information which are not spatially coincide with each other. During manipulation of a system by hands, haptic feedback is presented at user's hands. To improve the effectiveness of tissue stiffness and abnormality localisation, haptic and visual information should be presented at the same active point of interaction using direct touch interaction. Thus, to improve the performance at the next step, we propose to utilize direct touch which let user feel as though their finger is immersed in the screen to manipulate virtual tissue by using pressure-sensitive tablet. In contrast with available pseudo-haptic developments for palpation, this research is aimed to produce pseudo-haptic feedback with spatially coincide visual-haptic information, compact, mobile, wireless, and easy to manipulate for more effective interaction.

IV. Conclusion

This paper presented a novel method to apply pseudo-haptic feedback in soft tissue stiffness simulation for palpation by using an inexpensive 2D haptic surface. This method was evaluated for tumor localization. Analyzing the evaluation tests, we saw that participants were able to notice the stiffness differences among different areas. It proves that the pressure-sensitive touchpad can be used to express tissue stiffness haptic information during palpation simulation. In the future, a pressure-sensitive tablet will be used for a better immersive illusion through direct touch.

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References

[1] T. Endo, H. Kawasaki, T. Mouri, Y. Doi, T. Yoshida, Y. Ishigure, H. Shimomura, M. Matsumura, and K. Koketsu, "Five-fingered haptic interface robot: HIRO III," World Haptics 2009 Third Joint EuroHaptics conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, vol. 4, no. 1, pp. 458–463, 2009.

[2] A. Lecuyer, S. Coquillart, A. Kheddar, P. Richard, and P. Coiffet, "Pseudo-haptic feedback: can isometric input devices simulate force feedback?," in Proceedings IEEE Virtual Reality 2000 (Cat. No.00CB37048), 2000, pp. 83–90.

[3] M. Li, H. Liu, L. D. Seneviratne, and K. Althoefer, "Tissue Stiffness Simulation and Abnormality Localization using Pseudo-Haptic Feedback," in IEEE international conference on robotics and Automation, 2012, pp. 5359–5364.

[4] M. Li, L. D. Seneviratne, P. Dasgupta, and K. A. Althoefer, "Virtual palpation system," in International Conference on Intelligent Robots and Systems workshop "Learning and Interaction in Haptic Robots", 2012.

[5] H. Liu, J. Li, X. Song, L. D. Seneviratne, and K. Althoefer, "Rolling Indentation Probe for Tissue Abnormality Identification During Minimally Invasive Surgery," IEEE Transactions on Robotics, vol. 27, no. 3, pp. 450–460, 2011.