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Pseudo-haptics for rigid tool/soft surface interaction feedback in virtual environments

Min Li [a,*], Maisarah B. Ridzuan [a], Sina Sareh [a], Lakmal D. Seneviratne [a,c], Prokar Dasgupta [b], Kaspar Althoefer [a]

[a] Centre for Robotics Research (CoRe), Department of Informatics, Kings College London, London WC2R 2LS, UK
[b] Medical Research Council (MRC) Centre for Transplantation, King's College London, King's Health Partners, Guy's Hospital, London SE1 9RT, UK
[c] College of Engineering, Khalifa University of Science, Technology and Research, Abu Dhabi, United Arab Emirates

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ABSTRACT

This paper proposes a novel pseudo-haptic soft surface stiffness simulation technique achieved by displaying the deformation of the soft surface and maneuvering an indenter avatar over a virtual soft surface by means of a touch-sensitive tablet. The visual feedback of the surface deformation and the alterations to the indenter avatar behavior produced by the proposed technique create the illusion of interaction with a hard inclusion embedded in the virtual soft surface. The proposed pseudo-haptics technique is validated with a series of experiments conducted by employing a tablet computer with an S-pen input and a tablet computer with a bare finger input. Tablet computers provide unique opportunities for presenting the pseudo-haptic (indenter avatar speed), haptic (contact reaction force from the device surface) and visual cues (surface information) at the same active point of interaction which facilitates information fusion. Hence, here, we evaluate the performance of tablet computers in identification of hard inclusions within virtual soft objects and compare it with the performance of a touchpad input device. A direct hand-soft surface interaction is used for benchmarking of this study. We found that compared with using a touchpad, both the sensitivity and the positive predictive value of the hard inclusion detection can be significantly improved by 33.3% and 13.9%, respectively, by employing tablet computers. Using tablet computers could produce results comparable to the direct hand-soft surface interaction in detecting hard inclusions in a soft object. The experimental results presented here confirm the potential of the proposed technique for conveying haptic information in rigid tool/soft surface interaction in virtual environments.

1. Introduction

Pseudo-haptic methods create an illusion of haptic feedback via a visual display [1–4] without the need for the use of relatively complex, bulky and expensive haptic devices [5]. The modification of speed and size of the cursor for simulating bumps and holes using a computer mouse and a desktop computer was proposed by Lécuyer et al. [6]. By applying this method, image textures on the screen can be pseudo-haptically explored using a computer and a computer mouse. Shiota and Kashihara [7] proposed to generate pseudo-haptic feedback from drag operations on an iPad. The virtual object generally follows the finger movement. If the object moves slower in comparison with the finger movement, the user can feel the object is heavy. Thus, pseudo-haptic methods provide possible low-cost solutions for more realistic experiences in interactive virtual environments e.g. video games. In our previous research, this two-dimensional (2D) pseudo-haptic feedback was applied to soft tissue stiffness simulation [8]. The 2D hand motion was input by using a computer mouse while the visual information was displayed on a computer screen. By reducing the ratio between the indenter avatar (cursor) displacement and the input device (computer mouse) displacement, a resistance to motion when the indenter approaches an embedded hard nodule in soft tissue during sliding palpation was successfully simulated.

Rigid tool/soft surface interactions contain both indenting and sliding behaviors. To simulate indenting behavior, the input of a third dimension of motion or force needs to be enabled. With the aid of pressure-sensitive technology, touchscreens can detect different force levels applied by the user to the surface. Sinclair et al. [9,10] developed a 3D touchscreen with force feedback and

* Corresponding author. Tel.: +44 (0)2078482902.
E-mail addresses: min.m.li@kcl.ac.uk, min.m.li0012@gmail.com (M. Li), maisarah_binti.ridzuan@kcl.ac.uk (M.B. Ridzuan), sina.sareh@kcl.ac.uk (S. Sareh), lakmal.seneviratne@kcl.ac.uk (L.D. Seneviratne), prokarurol@gmail.com (P. Dasgupta), k.althoefer@kcl.ac.uk (K. Althoefer).

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haptic texture. This device detects contact forces and provides force feedback by robotically moving the screen along the z-axis, providing opportunities for the simulation of the stiffness property of soft surfaces. Therefore, they proposed applying this technique to enable surgeons to "palpate" brain tissue when touching and looking at the MRI brain scan. Apart from the possible applications in hospitals, this device also has promising applications in museums for interactive experiences with untouchable, valuable art works and antiques. However, it is difficult to integrate this technique into compact, mobile, and wireless handheld devices that are becoming increasingly popular, e.g. tablet computers and smart phones.

When interactions happen between a rigid tool and a soft surface, deformations occur at the soft surface side, where the change in the indentation depth and the deformation of the surface provide clues on the stiffness property of the surface [8]. To provide a more realistic feedback during rigid tool/soft surface interaction, visual feedback of tissue surface deformation is needed [11]. However, tissue surface deformation was not displayed in the aforementioned other feedback methods.

The implementation of pseudo-haptic feedback and providing visual feedback of the soft surface deformation in portable devices such as smart phones and tablet computers is promising [2,12]. However, it is concerned by the poor pressure-sensitivity of some smart phones and tablet computers. Therefore, in some cases, separate pressure-sensitive input devices were introduced and the haptic interaction and the visual information were presented at different locations. For instance, Kimura and Nojima [2] has used a smart phone enhanced with two film-type force sensors to create an illusory sense of softness. This was realized by resizing of the rectangle displayed on the phone when the user squeezes the phone. Kokubun et al. [12] displayed the deformation of the black and white polygons-formed surface on a smart phone to generate pseudo-haptic sensations when pushing on a separate rear touch interface. Ridzuan et al. [13] proposed to convey stiffness information of soft surfaces by modifying the visual deformation depth of a virtual surface in accordance with the contact force and the stiffness property of the soft surfaces. This was implemented by using a tablet computer and strain gauges placed on both left and right sides of the support plate underneath. Compared to the other aforementioned pseudo-haptic methods, in Ridzuan et al. [13]'s system, the haptic and visual information was presented at the same active point of interaction when using a tablet computer. This made the users feel as though their finger or the stylus could penetrate the pressure-sensitive surface and be extended into the digital world to manipulate virtual tissues behind the screens directly which is called immersive illusion [13,14]. According to their experimental results, this method can produce a similar stiffness sensation as perceived when interacting with real soft surfaces. However, each virtual sample was assigned with one homogeneous stiffness property and only vertical interaction (indentation behavior) with the virtual surface was enabled during their experiments. In order to reduce the complexity of the system caused by a separate pressure-sensitive input device, tablet computers with higher quality of the pressure-sensitivity should be employed.

In this paper, we propose to combine the sliding and indenting rigid tool/soft surface interactions to convey a non-homogeneously distributed stiffness property of soft surface. This is implemented by integrating the pseudo-haptic feedback described in our previous report [8] with the visualization of soft surface deformation and employing tablet computers. Soft surface stiffness data is acquired using a rolling/sliding indentation method [15–18] and then conveyed using a force-sensitive tablet computer. The major advantage of the proposed technique is that both the haptic and visual cues are presented at the same active point of interaction. Other advantages include compactness, portability, wireless operation, ease-of-use and low cost. The effectiveness of the proposed technique is evaluated by the measure of its ability to identify hard inclusions within soft surfaces in a simulation. In order to demonstrate the beneficial effects of immersive illusion [13,14] on pseudo-haptic sensation, we compare the performance of tablet computers in identification of hard inclusions with a touchpad input device. Note that in the case of using a touchpad input device, the contact force is exerted from the touchpad while the visual information is displayed on a computer screen. Here, hand-soft surface interaction was used for experimental benchmarking. The potential applications of our approach range from interactive gaming to medical training.

In Section 2.1, two types of reaction forces between the rigid tool tip and soft surfaces are simulated. Sections 2.2 and 2.3 explain the concept and algorithm of applying pseudo-haptics to the soft surface stiffness simulation and the hard inclusions identification process by using a force-sensitive tablet computer and a force-sensitive touchpad. Section 3 describes the process of soft surface stiffness data acquisition, the validation test protocol; Section 4 presents the results of the validation studies. Conclusions are described in Section 5.

2. Methodology

2.1. Rigid tool/soft surface interaction

The soft surface stiffness 3D haptic data which is used for the purposes of this paper comes from the rolling/sliding indentation method introduced by [15–18] to detect tissue abnormalities.

The rolling indentation method works as follows:

During the superficial rolling/sliding, the indenter slides over a soft object surface. As the indenter approaches a hard inclusion embedded in the soft object an increase of lateral force f_x is experienced (see Fig. 1). During indenting behavior, a tool is pressed on the surface of the soft object to explore its stiffness pattern. The reaction force f_y increases as the indentation depth increases. When the areas with hard inclusions underneath are pressed, the reaction forces are greater than those of other areas which are free from inclusions. In our previous research [8], the lateral reaction force f_x of the rolling behavior and the normal reaction force f_y of the indenting behavior were simulated and visualized separately. In this study, we have implemented simultaneous simulation of the two forces f_x and f_y to provide a more intuitive visual feedback to the user.

2.2. Pseudo-haptic soft surface stiffness simulation using tablet computers

When the user moves the input pen or his/her finger on the tablet screen towards a relatively stiffer area from P_o to P, the indenter avatar moves slower following the input (see Fig. 2), and an illusion of resistance to motion will be experienced. In this way, the virtual

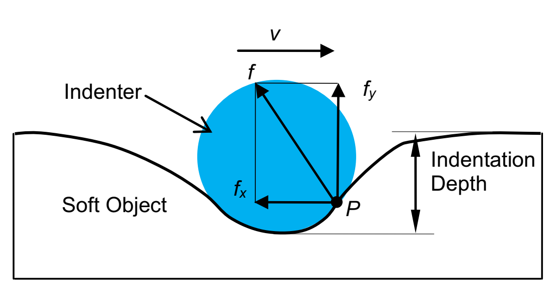

Fig. 1. Reaction forces in rigid tool/soft surface interaction.