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Fast hand skin deformation simulation of Digital Hand based on a nonlinear elasticity model

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Skin contact deformation of grasp provides useful information such as contact force, contact area, and contact pressure distribution for ergonomic assessment of handheld products. In this paper, a nonlinear elasticity model was proposed to simulate the skin contact deformation. A fast hand-skin deformation was developed for imitating the physical contact behavior. A hand surface skin anatomical partition was presented for being able to specify different physical properties in them and for efficient simulation for the ergonomic assessment of grasp ability. The realistic and fast contact deformations of grasp could be realized. The verification results showed that the proposed model could approximate the deformation in the acceptable range for virtual ergonomic assessment.

1.Introduction

The biomechanical property of hand skin plays a fundamental role in the tactile sense of humans. Therefore hand skin deformation simulation is valuable in virtual ergonomic assessments. The purpose of this research is to realize fast hand-skin deformation simulation in contact in our proposed Digital Hand[1]. To achieve the goal, we made the following contributions: 1) a nonlinear elasticity model of hand skin deformation is proposed, 2) the property of compressing-swelling effect of hand skin deformation is measured and reflected to the deformation model, 3) A partition of hand surface is proposed for accuracy and efficiency, 4) A efficient contact solving method is introduced, and 5) Efficient skin deformation simulation of grasping postures is realized.

2. Fast hand-skin deformation process

As shown in Fig.1, realizing fast hand-skin deformation in contact is composed of two main parts: 1) Constructing a physical model of skin contact deformation, and 2) Simulating hand skin deformation in contact.

2.1 Physical Model of Skin Contact Deformation

A physical model of skin contact deformation based on Boussinesq approximation is introduced. And nonlinear elasticity and compressing-swelling effect are extended for enabling more realistic simulation [2] according to the following two reasons: 1) human skin has complicated structure and presents nonlinear elasticity in the stress-strain relationship, and 2) human skin is a quasi-incompressible material, so that compressive force will cause regional volume swelling.

2.2 Simulating Hand Skin Deformation

Based on the proposed physical model, an algorithm to simulate an deformable hand is developed. As shown in Fig.1, the algorithm includes pre-process and online process. In pre-process, hand surface of a Digital Hand model is partitioned based on hand surface anatomical knowledge for accuracy and efficiency (A1). Then, we introduce the point-force-based discretization, in order to calculate response matrices between vertices in each partitioned surface based on proposed physical model (A2). For one Digital Hand model, the pre-process can be executed only once.

While in the online process, a collision detection algorithm is used to find collision regions between Digital Hand and product model surface (A3), and then, under the concept of quasi-rigid object, they are locally enlarged to get active regions (A4). Finally, based on the calculated response matrices in pre-process, the contact deformations over active regions were estimated by solving LCP (Linear Complementarity Problem) (A5).

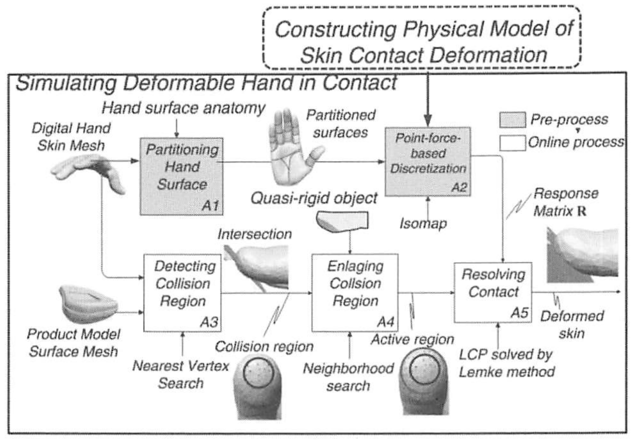
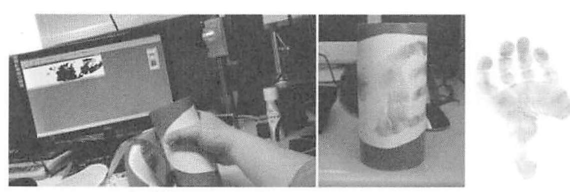


Figure.1 *Realizing fast hand-skin deformation in contact*

(a) (b) (c)

Figure.2 *Similar grasp postures griping a cylinder of ϕ 48mm. (a) MRI measured grasp posture, (b) Real grasp posture photo, (c) Simulated grasp posture generated by Digital Hand*



(a) (b) (c)

Figure.3 *Experiment verifying pressure distribution of grasp posture. (a) FSCAN system, (b) Sensors mat covered by handprint, (c) Handprint*

3. Simulation and Experimental Verifications

Simulating grasp posture with hand skin contact deformation is a valuable application of the Digital Hand. In order to verify the simulated skin deformation in grasping postures, as shown in Fig.2(a), a subject (male, age 27, right hand) was asked to take a MRI measurement to obtain a hand posture grasping a set of cylinders whose diameter were ϕ48mm, 60mm, and 100mm. As shown in Fig.3, the subject also asked to take pressure distribution measurements using sheet type pressure sensor (NITTA FSCAN) with 4.2 sensors/cm^2 (Fig.3 (a)) in the same

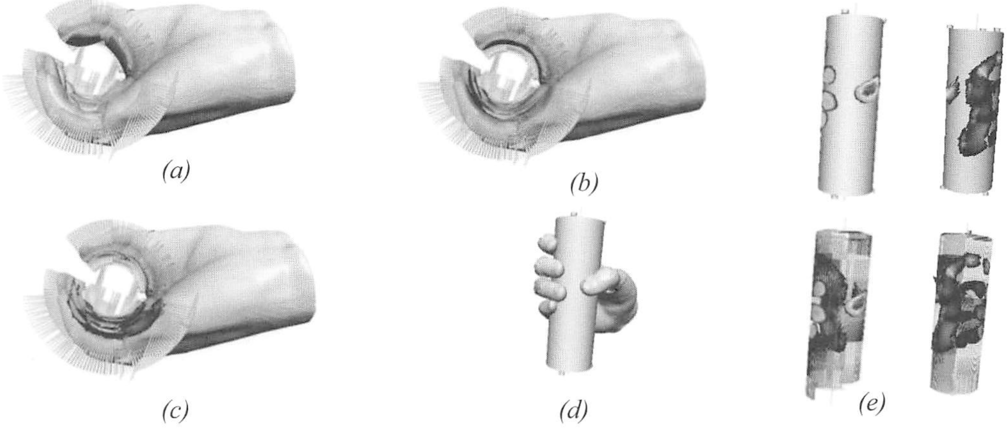


Figure.4 *Simulation of grasp posture griping a ϕ 48mm cylinder. (a) Skin before deformation, (b) Skin after deformation, (c) Estimated pressure distribution map, (d)Grasp posture from another view, (e) Estimated pressure distribution map from various views*

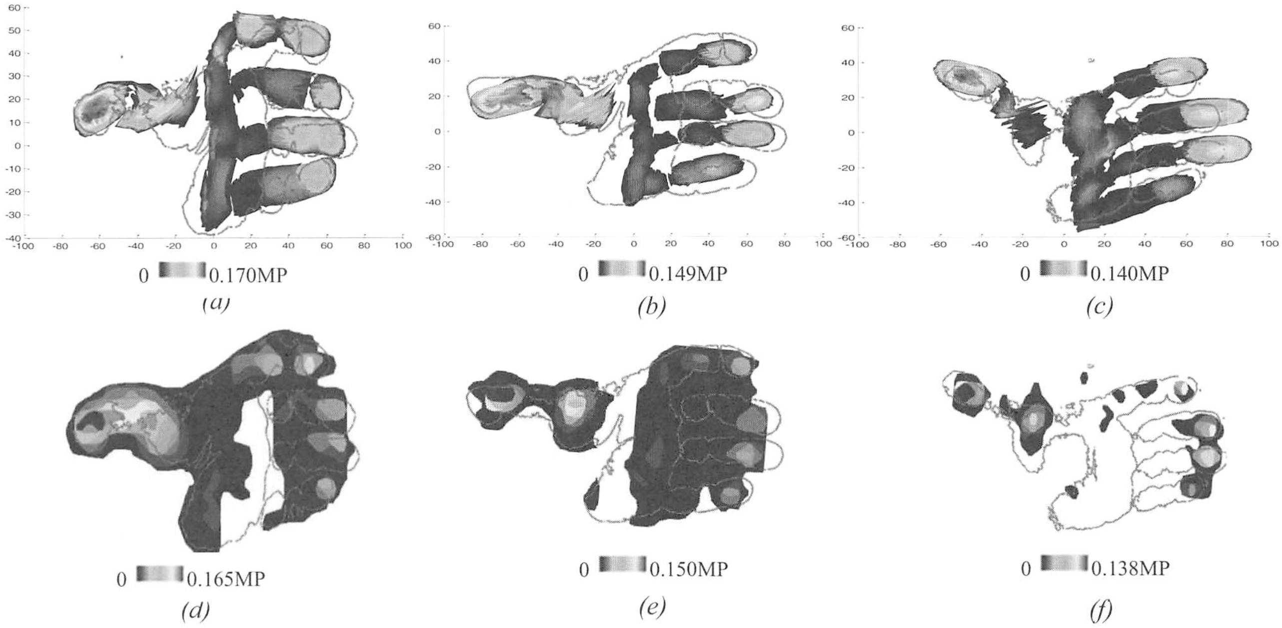


Figure.5 *Pressure distribution verification. Red boundary is contour of handprint. (a), (b) and (c)Simulated pressure distribution (from left to right: ϕ 48mm, ϕ 60mm,and ϕ 100mm), (d), (e) and (f) Measured pressure distribution (from left to right: ϕ 48mm, ϕ 60mm,and ϕ 100mm).*

grasping postures (48mm cylinder grasp) as shown in Fig.2 (b), so that the grasp fits to the handprint marks of the MRI measurements Fig.2 (a). On the other hand, a Digital Hand model of the same subject was made from the MRI measurements. The grasp posture of the Digital Hand model was reconstructed so that the bone meshes and skin surface mesh of the model fitted with the ones in the cylinder grasp in MRI measurements. As a result, very similar grasp postures (Fig.2 (c)) of the Digital Hand to the experimental ones was generated.

Fig.4 shows the visual skin deformation effect of the hand in grasp with the ϕ 48mm cylinder. Fig.4 (a) shows the hand skin before deformation. As shown in Fig.4 (b), the Digital Hand touched the cylinder surface without interpenetration. Fig.4 (c) and (e) shows the simulated pressure distribution map in different views obtained by our model.

As to computation efficiency, 19×2 response matrices were pre-computed in about 1 hour according to the partition of hand surface. The online process for one skin deformation in grasp was about 100s.

The measured pressure distributions by sheet type pressure sensor and handprints were used to verify the simulated pressure distribution, and contact force, contact area. In Fig.5 the extended estimated pressure distribution maps from 3D cylinder surfaces (Fig.5 (a), (b) and (c)) were compared with measured ones (Fig.5 (d), (e) and (f)). From Fig.5, the positions of local high pressures between simulation and measurement were very close to each other. In the different grasping postures, our simulated peak pressure, average pressure, normal force were similar with the measured ones. As to the contact area, their overlaps between simulation and handprints account for larger percentage (67% - 77%) of the hand prints.

Reference:

[1] Y. Endo, S. Kanai, et al., Virtual Ergonomic Assessment on Handheld Products based on Virtual Grasping by Digital Hand, SAE Inter. J. of Passenger Cars. 1 (2009) 590-598.

[2] Yulai Xie, S. Kanai, et al.: " Efficient simulation of human hand skin deformation based on a nonlinear elasticity model for virtual ergonomic assessment ", Proc. of JSPE Autumn, (2012).