1. Introduction
Rapid development of data acquisition technology like 3D scanners makes it possible to obtain geometry information of highly complex objects at high speed and with good accuracy. For the realistic haptic interaction with these objects, we propose an interactive efficient haptic reshaping and material property modeling. The proposed modeling supports not only a physically-based reshaping of very complex objects such as a real human face captured from 3D scanner but also efficient modeling of material properties such as roughness, stiffness, and friction.

2. Shape and Material Property Modeling
2.1 Shape Modeling by Haptic Deformation
Haptic reshaping requires three procedures: collision detection, deformation, and force computation. The collision detection process determines whether the haptic probe is within the virtual object. Since a point-based haptic interaction generally occurs between a haptic probe and a very small portion of the virtual environment, only the local geometry near the probe is required to accomplish collision detection. For performing collision check, we utilized local depth information coming from graphics hardware [1]. With local depth information, a collision between the probe’s position and a portion of the object can be easily detected through depth comparison. Computation of both deformation force and displacement of $i \text{th}$ vertex point can be done with the linear spring-mass (See Fig. (a)) formulation where $k_{ij}$ shows the force vector defined by spring stiffness, $l_{ij}$ is the rest length, $m_i$ is the mass, $d_i$ is damping, and $F_j$ is the external forces. $g_{ij}$ is collision detection and $p_i$ is position. Dimensions of position and spring matrix may be determined by the local deformation region for example hemispherical region. Therefore, simulation rate of position and force can be very fast.

2.2 Image-based Material Property Modeling
In addition to the shape modeling of objects, surface property modeling is also important for natural interaction with a virtual environment. Roughness, stiffness, and friction are three major surface properties of the most physical objects. Contrast to the existing surface modeling approaches in which simple analytical functions such as sine/cosine functions or some computations on the surface models are needed, the proposed surface property modeling is based on the Image-Based Representation (IBR) (See Fig. (b)). The IBR uses a set of reference images covering whole visible surfaces of the object. For roughness modeling, the roughness IBR buffer is created by combining geometric primitives such as a hexahedron, pyramid, sphere with Gaussian shape. Both stiffness and friction (static and dynamic friction) properties are not only modeled by the user and then are stored at the stiffness and friction IBR buffer respectively. After modeling each property, the IBR buffer is used for computing contact force. Roughness IBR buffer generates fine geometry shape on the original geometry shape. The other buffers are used for generating effect forces when the user touches the object with a haptic interface. In the haptic rendering point of view, the IBR on the object not only make it possible to realize fast collision detection with local depth information, but also enable to reduce the memory usage efficiently. Furthermore, the proposed IBR-based method is independent of the shape complexity and texture mapping method.

3. Conclusion
An efficient interactive haptic reshaping and material property modeling were proposed. A real human face containing 372,210 vertices obtained by 3D scanner [2] had been reshaped for plastic surgery planning with the proposed modeling techniques. In this example, computational cost of reshaping and surface exploration process is less than 0.22 and 0.073 msec. respectively (See Fig. (c)). Therefore, the proposed modeling not only allows users to interact naturally with very complex objects but also provides material property modeling by painting on the object’s surface through a haptic interface. The next phases of this work are acquiring real material properties by using mechanical sensors, extending our system to an elaborate graphic and haptic co-location workspace in order to provide more natural interaction between graphic and haptic interaction.

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