Finger Sculpting with Digital Clay:

3D Shape Input and Output through a Computer-Controlled Real Surface

Jarek Rossignac, *College of Computing & GVU Center*
Mark Allen, *School of Electrical & Computer Engineering*
Wayne J. Book, *Woodruff School of Mechanical Engineering*
Ari Glezer, *Woodruff School of Mechanical Engineering*
Imme Ebert-Uphoff, *Woodruff School of Mechanical Engineering*
Chris Shaw, *College of Computing & GVU Center*
David Rosen, *Woodruff School of Mechanical Engineering*
Stephen Askins, *Woodruff School of Mechanical Engineering*
Jing Bai, *School of Electrical & Computer Engineering*
Paul Bosscher, *Woodruff School of Mechanical Engineering*
Joshua Gargus, *College of Computing & GVU Center*
ByungMoon Kim, *College of Computing & GVU Center*
Ignacio Llamas, *College of Computing & GVU Center*
Austina Nguyen, *Woodruff School of Mechanical Engineering*
Guang Yuan, *School of Electrical & Computer Engineering*
Haihong Zhu, *Woodruff School of Mechanical Engineering*
Georgia Institute of Technology, Atlanta, Georgia, USA

Abstract

The NSF Digital Clay project is focused on the design, prototyping, integration, and validation of a computer-controlled physical device capable of taking any of a wide range of possible shapes in response to changes in a digital 3D model or to changes in the pressure exercised upon it by human hands. Although it clearly is a natural and unavoidable evolution of 3D graphical user interfaces, its unprecedented capabilities constitute a major leap in technologies and paradigms for 3D display, for 3D input, and for collaborative 3D design. In this paper, we provide an overview of the Digital Clay project and discuss the challenges, design choices, and initial solutions for a new Finger Sculpting interface designed for the Digital Clay and prototyped using conventional 3D I/O hardware.

1. Overview of the Digital Clay project

The ambitious interdisciplinary Digital Clay project, funded at the Georgia Institute of Technology by an NSF/ITR grant [1], brings together faculty members from Mechanical Engineering (Wayne Book, who is the PI, Imme Ebert-Uphoff, David Rosen, Ari Glezer), from Electrical and Computer Engineering (Mark Allen), from Architecture (John Goldthwaite), and from the College of Computing (Jarek Rossignac, Chris Shaw) and their students and collaborators. The project is focused on building a prototype of a computer controlled physical surface that may be touched and altered by human hands.

Figure 1: Sculpting with real clay

The objective is not limited to the simulation of the interaction between a sculptor and a passive lump of clay [2], as shown in Fig. 1, but is to transcend reality and endow the Digital Clay with proactive powers, allowing it to actively change its shape to reflect changes in a digital 3D model, to sense the pressure of bare human hands and to track their motion, and to intelligently react to this pressure by opposing a force that conveys prescribed stiffness properties and by altering its shape and the associated 3D digital model to support a variety of intuitive, global or local shape editing operations.

Thus, if successful, the Digital Clay will pioneer a new generation of haptic devices for bare-hands touch-based input and output interaction with 3D shapes. We hope to explore collaborative applications in Computer

Aided Design, architecture, art, medical training, and assistance to the visually impaired. For instance, Digital Clay will allow two remotely located users to simultaneously sculpt the same object. Each user will have a version of the Digital Clay that has the form of a shared 3D model. Finger pressures of one user will alter the local shape, which will alter the computer model, which will be transmitted to the other location, which will alter the other shape.

2. Hardware issues and design challenges

The current orientation of the Digital Clay project has resulted from several fundamental design decisions.

The first decision was concerned with the nature of the actuators that will give the Digital Clay the power to alter its shape and to exert a resistive force upon the user's hands. In order to achieve the desired compromise between the required power and degree of miniaturization, we have opted for hydraulic actuators, rather than electric ones. This decision has made it necessary to carefully design our own valves, which will be integrated in a high density matrix and will control the delivery of hydraulic power from the master fluid reservoirs to the individual actuators.

Figure 2: A toy version of the Bed-of-Nails

The second decision was concerned with the layout and function of the actuators. We have opted to pursue two prototypes. The first one is the Bed-of-Nails, which is best defined as a high resolution computer controlled version of the pinhead toy depicted in Fig. 2. The matrix of actuators will be arranged on a two-dimensional horizontal grid. Each one will control the height of a vertical piston. The family of shapes that may be taken by the Bed-of-Nails are restricted to height fields of a limited range. The advantage of this incarnation is that it simplifies the hardware-software interface, as the height of each piston may be controlled by reading directly from a z-buffer, which is present in all modern graphics processors and easily controlled through advanced 3D rendering APIs, such as OpenGL.

Thus, the Bed-of-Nails may be viewed as a 3D screen, where each pixel has a physical depth.

The second option is the Formable-Crust [3], where the hydraulic power is delivered through tubes to inflatable bubbles that control the joint angles between pairs of adjacent triangles of an articulated mesh mechanism, invented by Dr. Ebert-Uphoff and her student Paul Bosscher, of which a small prototype is shown in Fig. 3.

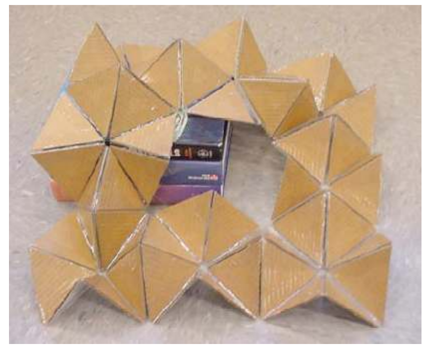

Figure 3: A Formable-Crust prototype

Dr. David Rosen and his student, Austina Nguyen, have explored new materials suitable for manufacturing the compliant joints of such articulated structures through a Stereo-lithography deposition process. One of the early prototypes is shown in Fig 4.

Figure 4: A candidate for a spherical joint

The third decision concerns the choice of sensors. Dr Ari Glezer and his students are exploring whether carefully chosen fluids and precise calibration of the fluidic cells (pistons/bubbles), valves, fluidic channels, and reservoirs will permit to use temporal integration of pressure to estimate the elevation of a piston or angle of a joint.

The pressure sensors and the MEMS valves will be integrated into a back-plate, which will be connected to the actuators through laminate-based pipes. The design of the micro-valves, sensors, pipes and actuators, is carried along with the design of the associated manufacturing processes by Dr. Mark Allen and his colleagues.

Dr. Wayne Book and his colleague, Haihong Zhu, have been exploring scalable control strategies for the actuators and sensors [4]. With his student, Stephen Askins and colleagues from the ENSAM in France, Dr Books has developed a simulation of the skin to cover the Bed-of-Nails version of the Digital Clay, see Fig. 5.

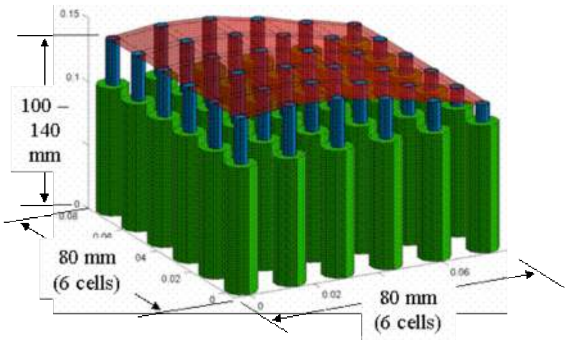

Figure 5: Skin stretched over the Nails

Finally, Drs. Jarek Rossignac and Chris Shaw and their students are focused on designing and prototyping the model of an effective interface between the human fingers and the surface. Starting from the nature of the contact: How will the surface know when you push it? How will it know that you want to pull it out? How much resistance should it offer?

With Josh Gargus, they have developed models for this contact behavior and have simulated them on a Phantom force-feedback haptic device, so that we can validate and fine-tune the models before the actual Digital Clay hardware is operational. We hope that the resulting approach [5] will enable the Digital Clay to track naked fingers and provide force and visual feedback to the user (see Fig. 6).

The next question is: How do you control the shape of the surface of the Digital Clay? With Ignacio Llamas and Byung-Moon Kim, they have explored an intuitive approach which mimics temporarily “gluing” two handles to the surface and then using them to simultaneously drag and rotate the corresponding surface points and the associated surface normals and tangents. The "Twister" shape editor [6] has been developed to prototype this approach using two Polhemus trackers through which the user can attach the handles to the model and then simultaneously stretch, twist, and bend the surface of a digital model of a 3D object. We have devised a new approach [6] that automatically computes a Free Form Deformation that simultaneously interpolates the corresponding 12 position and orientation constraints, with a smooth decaying effect away from the grabbed portions (see Fig. 7 and 8).

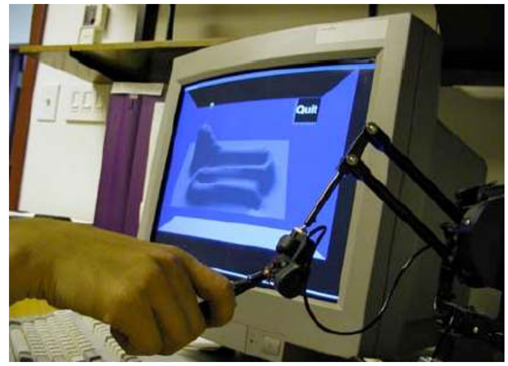

Figure 6: Validation of dynamic interaction

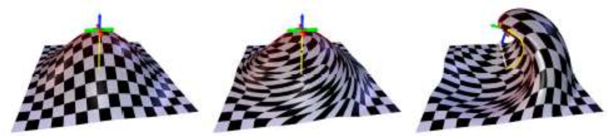

Figure 7: One hand pull and twist deformation

Figure 8: Two hand deformation

3. Acknowledgements

The Digital Clay project has been funded by the National Science Foundation, ITR Grant IIS-0121663. The Finger Sculpting effort has been in part supported by a Seed Grant from the GVU Center at Georgia Tech.

4. References

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