THE PLANK: Designing a simple haptic controller.

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Abstract
Active force-feedback holds the potential for precise and rapid controls. A high performance device can be built from a surplus disk drive and controlled from an inexpensive microcontroller. Our new design,The Plank has only one axis of force-feedback with limited range of motion. It is being used to explore methods of feeling and directly manipulating sound waves and spectra suitable for live performance of computer music.

Keywords
Haptics, music controllers, scanned synthesis.

INTRODUCTION
In 1996, Perry Cook at Princeton, Ben Knapp at San Jose State and Chris Chafe at Stanford University started teaching a video-linked course in human-computer interaction technology [1]. Max Mathews and Bill Verplank have in the last two years focussed the course on music controllers [2] for the masters program in music science and technology [3]. At CCRMA, we have a Phantom, a high-performance three-degree-of-freedom force-feedback device donated by Interval Research. We want a simpler device for experimentation and performance.

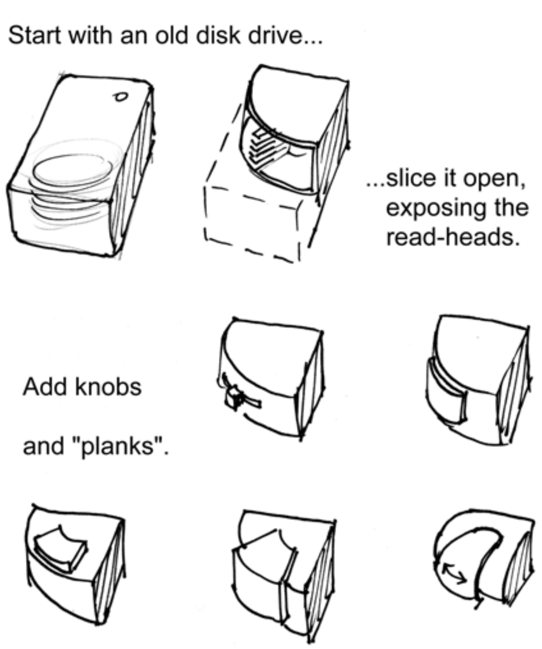

Figure 1. The Plank concept.

Scanned Synthesis
At Interval, we used Phantoms [4] to explore the value of force-feedback. One discovery was that simple spring-mass simulations, which are uncontrollable without force-feedback, can be controlled simply by letting the vibrating system transfer energy to the human. In feeling a simulated wave, Verplank, Shaw and Mathews had the idea of listening to the shapes. This came to be known as "scanned synthesis" [5]. The idea is to directly manipulate a dynamic wave shape at human-hand frequencies while scanning the wave shape out at audio frequencies. The pitch is determined by the length of the wave and the scan rate. The timbre is determined by the wave shape which is being continuously controlled by the performer.

Haptics
The term haptics is used by psychologists to describe the human sense of touch including skin senses as well as muscle and joint senses. Recently, "haptic" devices have made it to market in vibrating pagers, rumble-packs, force-feedback joysticks, steering wheels and mice. There are active research communities and a small industry building devices [6]. Standards have been established for communication and development [7]. At Interval, we explored the potential for simple haptic devices for media control and expression [8].

HAPTIC ILLUSIONS
The Plank is designed to take advantage of several illusions that allow us to reduce the device complexity while maintaining haptic fidelity. The key feature is a surface which measures forces orthogonal to its motion. With a measured surface force, the Plank simulates terrain as well as friction and dynamics.

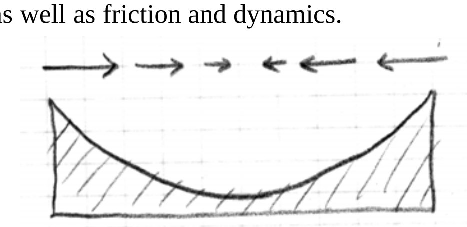

Figure 2. Slope Illusion

Slope
When you press down on a surface, it usually pushes back on you with a "surface normal" perpendicular to the surface. The forces fed back by the device can give the illusion of slopes of a surface. Small variations in force as you move along the surface are felt as bumps. In a

pioneering study, Margaret Minsky explored this phenomenon of simulated textures with a two-degree-of-freedom force-feedback joystick [8]. The Plank, reinforces this illusion by measuring the force applied by the user normal to the motion and making the tangential force-feedback proportional.

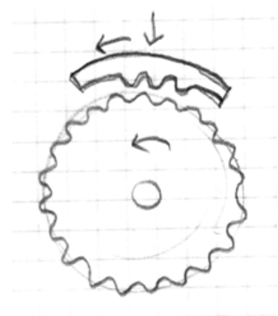

Figure 3. The Haptic Clutch.

Clutch

Rob Shaw [7] simulated a variety of dynamic systems which could be engaged by applying forces. We came to call this phenomenon the "haptic clutch". By pressing on The Plank, you engage with a simulated moving object. This technique compensates for the limited travel of The Plank and allows the illusion of wide reach.

Figure 4. Disk Drives before and after.

HARDWARE

The construction of The Plank was undertaken as an educational exercise using inexpensive or found components. It is described in some detail with the hope that others will take on such do-it-yourself haptics.

Motors

Rotary DC motors are the most common actuators used for haptic display from $1 vibrators to $100 joysticks to $10K Phantoms. In contrast, the motors chosen for The Plank are from computer disk drives where they position the read-heads. They are known as voice-coil motors. There is no requirement for gears or pulleys, both the drive and the sensor are directly coupled to the motor. Several haptic displays have been made from disk drive motors. Hong Tan studied tactile communication bandwidth with three independent disk-drive motors [10]. Pietro Butolo built a planar mechanism for positioning the tip of a stylus using three disk-drive motors [11]. The voice coil motors are readily available as cast-offs in crashed disks.

Microcontroller

To ensure rapid computation of the forces, an Atmel mega163 microcontroller is dedicated to local control of The Plank. It operates at up to 8 Mhz with 8 channels of 10-bit A/D (~10k samples/second), 32 I/0 ports, 16K bytes of program memory and 1024 bytes of data memory. The microcontroller has a UART for communication via MIDI with a synthesizer or real-time DSP software. Interrupts keep the sampling, or servo update at a steady rate up to 4kHz.

Sensing and orthogonal force control

A hall-effect sensor is used for rotary position feedback read by an 10-bit A/D converter built into the microcontroller. A 12-bit DAC commands a power op-amp for generating up to 3A current and forces up to 5 Newtons (~1 lb) at the finger tips (for short times). The sensing and power amp came from the design for a simple device used in teaching haptics [9]. Force-sensitive-resistors measure finger pressure on the surface of The Plank.

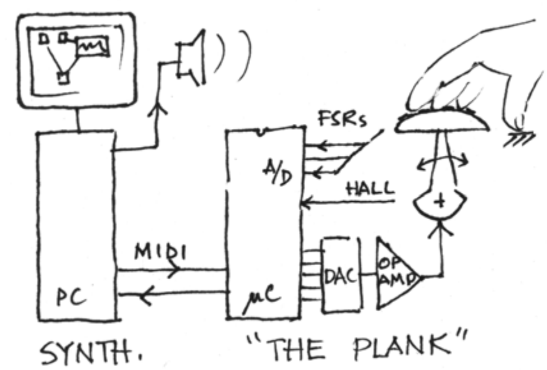

Figure 5. System diagram.

EFFECTS

Table of forces: Terrain

The microprocessor holds a small look-up table with a force for every measured position of The Plank. In scanned synthesis, the shape represents one cycle of a wave or piece of terrain. As you move The Plank, you feel the shape of the terrain; when you apply pressure, you can manipulate the terrain.

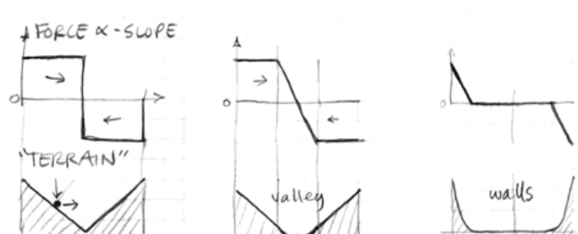

Figure 7. Forces create terrain illusions.

Motion: Dynamics
The whole terrain can be moved left or right (actually just a pointer into the table). Buffers can extend the table beyond the range of Plank motion (in the case of scanned synthesis, the table is circular and the buffers are not necessary). To simulate a single mass attached to a spring, one detent or deep valley in the terrain represents the position of the mass, its slopes represent the stiffness of the spring. The force on The Plank increases as it moves "up the slope of the valley". The acceleration of the mass is simply computed from the force being fed back to The Plank.

Friction
We have experimented using the Phantom with several friction models. The simplest is "stick-slip". Just one spring that builds up to a maximum and then "breaks" feels like plucking a string. When one spring breaks another can grab hold; many small ones make a fine texture that makes it easy to hold still. It is easy to add "viscosity" by measuring velocity and resisting the motion proportionately.

Combinations of these effects should be able to provide a wide variety of behaviors. Examples are shown in Table1.

Table 1. The Plank's Effects Combined

Effect	Terrain	Dynamics	Friction
DETENTS	Valleys	-	-
PLATTER	None	Inertia	Stick-slip
WAVE	Shape	Mass/Spring	Viscosity
PLUCK	-	String	Stick-slip

Figure 7. Hand positions.

PROGRESS AND PLANS
The hardware and microprocessor software are working in a rough prototype. We are not yet communicating with the synthesizer let alone producing music.

The Plank will be used to interface with scanned synthesis, and we will explore mappings of The Plank's interactions with wave terrains to audio parameters. An advantage of haptic interfaces for real-time music performance is that the performer now has another direct bidirectional interaction with the sound through his or her hands. We anticipate being able to simulate the feel of some traditional musical instruments (drums, piano, strings) allowing precise and fast control. We are also looking for new effects and unexpected, expressive sounds.

ACKNOWLEDGMENTS
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REFERENCES

[1] Cook, Perry, "Human-Computer Interface Technology". <http://www.cs.princeton.edu/courses/cs436>

[2] Verplank,B, Mathews, M., "A Course on Controllers," NIME 2000. <http://www.csl.sony.co.jp/person/poup/research/chi2000wshp/papers/verplank.pdf>

[3] CCRMA, "Masters degree in Music, Science and Technology,"< http://www-ccrma.stanford.edu/info/mst-info.html.>

[4] Massie, Thomas H. and J. K. Salisbury. 1994 "The PHANTOM Haptic Interface: A Device for Probing Virtual Objects" Proceedings of the ASME Winter Annual Meeting, Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, Chicago, IL. <http://www.sensable.com>

[5] Verplank, W., Mathews, M., Shaw, R., "Scanned Synthesis", ICMC, Berlin 2000. < http://www.billverplank.com/ScannedSynthesis.PDF>

[6] The Haptics Community Web Page, <http://haptic.mech.nwu.edu/>

[7] Immersion Corporation, "TouchSense Fundamentals" <http://www.immersion.com>

[8] Snibbe, S., MacLean, K., Shaw, R., Roderick, J., Verplank, W., Scheeff, M., "Haptic Metaphors for Digital Media," in Proc. of ACM Symp. on User Interface Software & Technology (UIST 2001), Orlando, FL, 2001 <http://www.cs.ubc.ca/~maclean/publics/uist01-HapticMedia.pdf>

[9] Minsky, M. D. R., "*Computational Haptics: The Sandpaper System for Synthesizing Texture for a Force-Feedback Display*." PhD thesis, MIT, June 1995.

[10] Tan, Hong Z., Rabinowitc, W.M., A New Muli-Finger Tactual Display", ASME DSC-Vol.58, 515-522, 1996. <http://hongtan.www.media.mit.edu/people/hongtan/hongtan-pub/conf/13ASM96.ps>

[11] Buttolo, P., Hwang, D.Y. "Hard Disk Actuators for Mini-Teleoperation" SPIE Telemanipulator and Telepresence Technologies Symposium, pp.55-61, 1994. <http://www-cdr.stanford.edu/Touch/publications/richard2_asme97.pdf>

[12] ATMEL, 8-bit RISC Microcontrollers, http://www.atmel.com/atmel/products/prod199.htm

[13] Richard, C., Okamura, A., Cutkosky, M. "Getting a Feel for Dynamics: using haptic interface kits for teaching dynamics and controls", 1997 ASME IMECE 6th Annual Symposium on Haptic Interfaces, Dallas, TX, Nov. 15-21. <http://www-cdr.stanford.edu/Touch/publications/richard2_asme97.pdf>