Low-Cost Malleable Surfaces with Multi-Touch Pressure Sensitivity

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Abstract

While touch sensitivity has today become commonplace, it is oftentimes limited to a single point of contact with a hard, rigid surface. We present a novel technique for the construction of a malleable surface with multi-touch sensitivity. The sensor is pressure sensitive and responds to near zero-force touch from any object. The technique is an extension of previous work based on frustrated total internal reflection.

1. Introduction

Touch screens have become a common input device; how-ever, most of today's systems can only detect a single point of contact. Multi-touch sensors exist, but are typically ex-pensive and difficult to construct. These systems also tend to be hard, rigid, flat surfaces which provide no haptic feedback. A recent development is the malleable touch surface [3][10][11]. These surfaces are characterized by a softer touch interface that provide passive haptic feedback and are pressure sensitive. They also provide a feeling of depth and tangibility that makes them well suited for 3D applications such as sculpting, molding, terrain deformation, etc.

We present a simple technique for the construction of a multi-touch sensitive display with a malleable surface. The technique detects near zero-force touch with any object and is highly sensitive to pressure. Additionally the surface can be made to a variable degree of softness and thickness, lending well to usage requiring deformability and feed-back, such as sculpting and massaging applications. The technique is an extension of Han's multi-touch sensor de-sign based on frustrated total internal reflection (FTIR), which is a technique commonly used in fingerprint readers [2].

2. Related Work

Multi-touch sensitive surfaces are found in various forms in many different technologies. A simple approach for multi-touch sensing is to deploy an array of discrete sensors. These sensors can operate entirely independently [9], through a connected set of independent active elements [4][12], or through a matrix of purely passive sensors [7][8]. However these approaches tend to suffer from poor resolution and are typically very complex to construct.

Vision-based systems have been proposed to provide higher resolution and support for malleable surface materials. These systems either approximate the 3D position of the user's hand through pixel intensity [6], stereoscopy [5][13], or through markers attached to a deformable material [3][10][11]. Using a deformable material has the added advantage of providing passive

Figure 1: Multi-touch sensitive surfaces are particularly useful for collaboration on large displays such as multi-user tabletops.

Figure 2: The pixel intensity grows as touch pressure grows. The left image is a zero-force touch, center is a light press, and right is a hard press.

haptic feedback and adds an element of depth to the interaction surface. Additionally, these surfaces typically report pressure as a vector, meaning touch pressure can be interpreted in directions not necessarily perpendicular to the interaction surface. However the markers on the deformable material must be opaque, meaning the system must be top-projected.

2.1. FTIR-Based Multi-touch Sensing

Han proposed a low-cost, simple FTIR-based sensor. The system introduces infrared (IR) light into a medium (typically acrylic) with an index of refraction significantly different than the air around it. When the light reaches the interface between the two mediums at an appropriate angle of incidence, it is reflected. However when the sensor is touched, the difference in the index of refraction between the two interfacing mediums (acrylic and skin/oil/sweat in this case) is reduced and the reflection is frustrated, causing the light to escape out the opposite side. This light can then been detected with an optical sensor such as an IR filtered camera or photodiode.

This approach suffers from a number of drawbacks. First, the system gives only a rough sense of pressure. The intensity of the frustration does not change significantly as the user presses more firmly; however the elasticity of the user's skin causes the radius of the touch contour to grow with pressure. This is effective for very coarse pressure sensitivity, but is severely limited by the resolution of the camera. Additionally, performance is severely degraded when the users' hands are dry. For example, we deployed an FTIR surface in the demo session of a large academic conference held in a cold, dry, mountainous region. We found the technique performed poorly for approximately half of users.

To address these issues Han proposed the use of a surface overlay with an FTIR sensor. Additionally the overlay material can serve as the display surface, removing the distance between the screen and the point at which the users' touch is sensed. Also, the use of a proper overlay reports touch as a continuous range of intensity rather than a binary value, which leads to greatly increased pressure sensitivity.

However Han suggests the use of simple vinyl rear projection screen as an overlay. We have found this material to be ineffective. The user must press quite hard to cause even minimal frustration, and the system suffers from severe hysteresis upon relaxation. Han reports a hysteresis of up to a full second; however our tests have yielded hysteresis up to 5 seconds. Additionally the material is flat and assumes the rigidity of the underlying acrylic.

3. FTIR with Malleable Surface Overlay

Our technique builds on Han's design by including a thick, soft surface overlay. The softness of the surface amplifies the pressure sensitivity of the sensor while providing an inviting user experience with passive feedback. Addition-ally, because users can "dig their hands" into the surface, the technique provides an interaction surface with a feeling of tangible depth. The surface is also sensitive to touch from any object, not just those with the appropriate optical properties. Additionally, the sensor will report the contour of the touch, enabling rough shape recognition.

The softness, scalability, and sensitivity to touch with any object are useful for tangible drawing applications. Finger-paint Plus (Figure 3) is a simple painting application that allows the user to paint using not only their hands, but also paint brushes, stamps, cookie cutters, etc. The large surface naturally supports collaborative painting, and the softness of the surface makes the sensor well suited for deployment into usage scenarios involving small children.

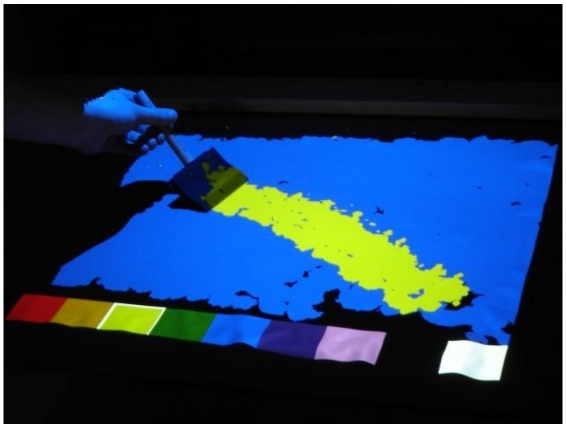

Figure 3: *Fingerpaint Plus* is an application that allows users to paint with any object. For example a user can perform strokes using a simple paintbrush.

Other potential applications of the surface include 3D terrain deformations, where users can tangibly create mountains and valleys by performing whole handed gestures while digging into the table surface. For example, a user could perform a “gathering” gesture where she draws her hands towards each other to create a mountain. Alternatively she could perform a “spreading” gesture by moving her hands apart to create a valley. Additionally use of familiar physical tools would be possible, such as using a spatula or whisk to “smooth” and “stir” the terrain, or heavy objects such as rocks and weights could be dropped onto the surface to create virtual impact craters.

3.1. Implementation

We chose to construct our surface overlay with silicone rubber. The material is inexpensive and widely available at most hobby shops. It is typically sold in liquid form as a molding material for physical product prototyping, but is also available in sheets. The material can be mixed to varying degrees of softness, comes in a variety of colors (including transparent), and forms to the shape of the mold in which it is poured. Silicone rubber makes an effective surface overlay for many reasons:

- **Malleable** – It can be mixed to practically any thickness and softness and will perform properly. Therefore soft, malleable touch surfaces similar in feel to a sponge or gym mat can be created as well as thin, rigid surfaces.
- **Moldable** – It is primarily sold as a casting material for plastic molds and therefore holds shape well. This makes the material well suited for applications where a non-planar or textured touch surface is desirable.
- **Improved Performance** – It is remarkably effective at causing the frustration effect when used with acrylic. When molded properly the system has effectively no hysteresis, a high sense of pressure sensitivity, and senses touches of near zero force.

On top of the rubber we placed a sheet of simple vinyl rear projection screen to serve at the display surface. Also, we found it necessary to mold a rough texture to the side of the surface overlay that touches the acrylic to reduce false positives and hysteresis. Implementations have been produced using both top and rear projection.

4. Performance

Informal evaluations have been used to determine system performance. Two separate tabletops were created: a thick, soft top-projected system and a thin, hard, rear-projected system. The top-projected system had an overlay approximately 1 cm thick and the softness of a gym mat. The thin system had an overlay less than 1 mm thick and felt as hard as a piece of acrylic. The thick system was top projected because even reportedly clear silicone rubber is partially cloudy and was found to distort the projection when poured to a thickness over a centimeter.

Both systems were found to provide touch sensitivity much more reliably than Han’s technique. Both systems could detect touches near zero-force. Additionally, the thickness and softness of the top projected system provided considerably more pressure sensitivity. The thick system could detect distinct pressures ranging from a light touch with a paint brush to a hard press with the thumb. However the thick system caused the contour of the contact to become “fuzzy”, making the thin system more appropriate for applications in need of shape recognition. Additionally, the poured silicone rubber was found to be rather heavy (~1 kilogram per Liter) and excessively thick systems might reduce the portability of the surface.

5. Future Work

Our future work will continue along two paths. First, we will explore new interactive surface designs that are now made possible through application of our technique. Additionally, we will seek to make the design more portable.

5.1. Textured Surfaces

An advantage to using a cast material is that the surface can be molded to fit any shape. This presents the possibility of some interesting design options. For example, regions of the screen can be given different textures. But-tons, for example, could be raised above the surrounding screen, or the texture of the material could be manipulated to represent the texture of the displayed content underneath it. For example, a 2D terrain might include a patch of ice which could be given a smooth texture, while a patch of dirt might be given a rough texture. More ambitiously, the shape of the surface could even be made to reflect a 3D terrain; such has having large mountains physically protruding up from the interaction surface.

5.2. Portable Displays

Currently the system requires a camera positioned behind the interaction surface, along with a means of projecting the display image. This makes the system somewhat large and requires an active calibration step upon setup. Han reports that a common LCD panel allows IR light to pass through [1]. We have verified this finding and are working to integrate an IR sensing device directly into the casing of an LCD display. A current promising approach is to re-place the camera with a mesh of IR sensitive photodiodes. This approach is similar in design to the device described in Lee et al. [4], and is analogous to embedding a very large monochrome Color Capture Device (CCD) directly into the display. The photodiode mesh would be the same size as the LCD panel, porous, and placed between the LCD and the backlight. This would increase system port-ability and greatly simplify system deployment by eliminating the need for a calibration step. A further refinement might include integration with an OLED display that re-quires no backlighting. Additionally, the photodiode mesh could be made flexible, allowing for possible integration with IR transparent flexible displays.

6. Acknowledgements

We wish to thank NECTAR and NSERC for funding sup-port of this work, along with the EQUIS Group at Queen's University and Gerald Morrison from Smart Technologies.

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