FiberBoard – Compact Multi-Touch Display Using Channeled Light

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ABSTRACT

Multi-touch displays based on infrared (IR) light offer many advantages over alternative technologies. Existing IR multi-touch devices either use complex custom electronic sensor arrays, or a camera that must be placed relatively distant from the display. FiberBoard is an easily constructed compact IR-sensing multi-touch display. Using an array of optical fibers, reflected IR light is channeled to a camera. As the fibers are flexible the camera is free to be positioned so as to minimize the depth of the device. The resulting display is around one tenth of the depth of a conventional camera-based multi-touch display. We describe our prototype, its novel calibration process, and virtual camera software based on existing multi-touch image processing tools.

Author Keywords

Multi-touch, infrared sensing, fiber optics.

ACM Classification Keywords

H5.2 [Information interfaces and presentation]: User Interfaces - Input devices and strategies.

INTRODUCTION AND CONTEXT

Multi-touch displays offer significant advantages over traditional single touch displays, for example, allowing concurrent shared use, bimanual interaction and multi-finger gestures. Until recently, multi-touch display systems have been used as research tools or in highly specialized applications (see Buxton [2] for a chronology of multi-touch sensing technologies). Public interest in multi-touch interaction has grown following the introduction of devices such as the Apple iPhone [1] and Microsoft Surface [8].

Furthermore, demonstrations by Jeff Han [3] widely popularized multi-touch implementations based on the principle of frustrated total internal reflection (FTIR). Infrared light (IR) is used as it lies outside the visible spectrum, and is unaffected by the light required for a display. A typical FTIR system consists of a projector, a projection screen, an IR-sensitive camera and an acrylic sheet with IR emitters. The IR light internally reflects within the sheet, and any points of contact (such as finger tips) diffusely scatter the light.

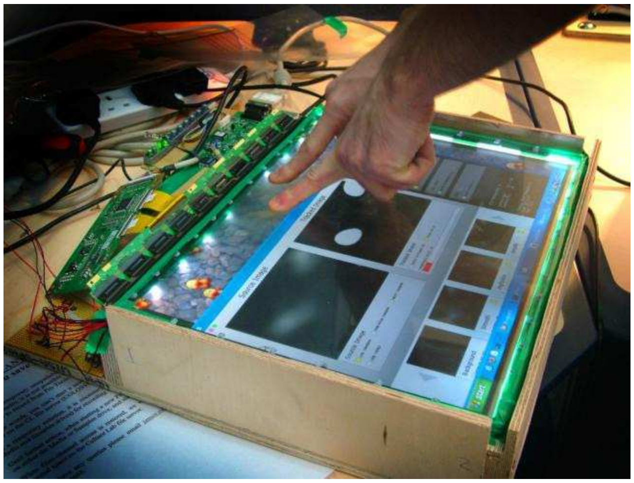

Figure 1. FiberBoard multi-touch LCD display showing processed touch image data from the channeled light.

The use of a projected display, and the distances required for both the projector's throw and the camera's optical path, give rise to constraints on the minimum size of such devices (proportional to the dimensions of the display). In practice the resulting bulky tabletop displays are likely to be unsuitable for many application contexts and there is a clear requirement for more compact versions. Although a liquid crystal display (LCD) can replace the projector and projection surface, reducing the camera's optical path is more difficult. One solution is to use multiple cameras, yet quadrupling the number of cameras only halves the necessary optical path.

Some resistive touch-screen overlays can be used to detect two touches (such as Tyco Electronics Elo TouchSystems, Resistive Gestures Touch Technology [12]). Capacitive panel multi-touch has been limited to smaller displays such as the Apple iPhone, although newer devices, such as

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N-trig's DuoSense Technology [9], are emerging for larger screens. Nevertheless, these technologies lack the capabilities of some IR-based systems, such as true multi-touch, near-surface tracking, and object shape extraction.

ThinSight [4, 6] is one promising solution: a specialized set of electronic boards containing a matrix of retro-reflective optosensors placed behind a conventional LCD display. IR reflective objects (such as fingers) in front of the screen reflect light back to the sensors. Hofer et al. [5] described FLATIR, a similar design that uses an FTIR surface as a light source instead of optosensor emitters. However, both designs rely on complex custom electronics and require layers of multiplexing to sample the sensors.

Tactex Kinotex sensors [11] use fiber optics to sense multiple touch points. In each element a transmit fiber emits light into a cellular foam layer, and any applied pressure increases the light level reflected to a receiving fiber. However, the sensing elements are opaque, and not suitable for use with a flat-panel display.

Yet the use of fiber optics allows considerable flexibility in the placement of a sensing array and in FiberBoard (Figure 1) we present a novel method for substantially reducing the size of an IR-sensing multi-touch display using only off-the-shelf components, reducing complexity and cost when compared to solutions requiring bespoke electronics.

FIBERBOARD

FiberBoard uses a two-dimensional matrix of optical fibers. The fibers channel light from each discrete sensing point and terminate in a bundle that is placed at the aperture of a digital camera. The resulting imaged pattern of light is decoded to produce a touch map, which can be further processed to determine and track multiple points of contact. As the fibers are flexible, the camera is free to be positioned so that the overall depth of the device is significantly reduced (see Figure 2). Where d is the length of a display diagonal and θ is the field of view of the camera, the minimum depth of a conventional camera-based multi-touch system (assuming mirrors are not used) is given by $d / 2 / \tan(\theta / 2)$. The camera's field of view places a significant constraint on the minimum display depth.

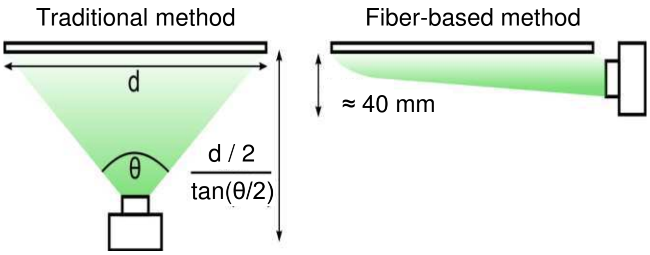


Figure 2. Channeling the light to the camera (right) can reduce the overall depth compared to traditional vision methods (left).

For example, a camera-lens system with a 60° field of view used with a 19" display requires a depth of around 420 mm. For a 40" display this increases to 880 mm. By contrast, the depth of FiberBoard is only constrained by the limit of the radius of curvature below which the fibers no longer act as a waveguide. The fibers in our 19" FiberBoard prototype extend around 40 mm below the LCD layer, and the overall stack is around 80 mm (excluding supporting frame).

FiberBoard uses a standard LCD screen for the display and a regularly spaced array of fibers is placed behind the backlighting panel. Infrared light and an IR sensitive camera are used, as the frequency lies outside the visible spectrum and avoids interference from the display. An FTIR layer mounted above the display provides a high contrast between touch points and any ambient IR light. An alternative arrangement would be to use diffuse illumination (DI), in which IR light reflects off anything placed on or near the surface, with some of this reflected light being channeled along the fibers. Additional fibers could be used to provide DI by channeling light at points on the display (see Figure 3).

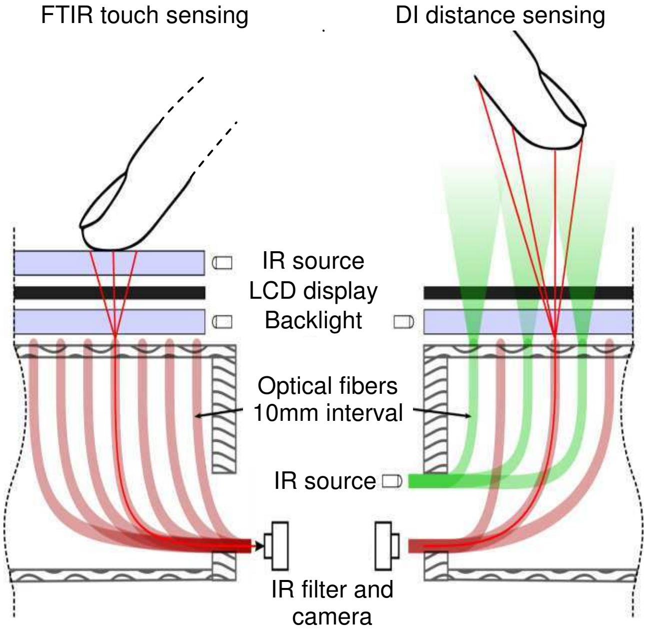


Figure 3. Illumination methods: an FTIR layer (left); channeled diffuse illumination to sense distance (right).

An automated calibration procedure determines the mapping between terminating fibers and display coordinates. At run-time, a software layer filters and presents the resulting data as a video capture device, allowing existing multi-touch software libraries to be used to further process the touch image. This capability of FiberBoard, to act as a virtual video capture device, allows us to leverage existing multi-touch software and is a key advantage of the technology.

IMPLEMENTATION

Our FiberBoard prototype (see Figure 4) is based on a standard 19" LCD display. To reduce ambient IR light incident on the sensing fibers, the fluorescent backlight (which emits IR) was replaced with an outer ring of white LEDs (an alternative would have been to filter out the IR light at source). Our priority for the prototype was achieving successful contact-based finger input: an acrylic FTIR layer was chosen to robustly highlight interactions on the surface, and a sensor pitch of 10 mm was selected based on favorable results from ThinSight [4, 6] and FLATIR [5].

Polymer optical fibers with 0.5 mm diameter and 10 mm minimum bend radius were placed into a drilled steel back plate at 10 mm intervals (40 × 30 = 1200 fibers are required to fully populate the matrix). The resulting array was placed behind the backlight and the fiber ends bundled together terminating at the camera. A removable band-pass IR filter was inserted between the fiber bundle and the camera.

The polymer fibers have a numerical aperture of 0.5, giving an angle of acceptance, θ, of $\sin^{-1} 0.5 = 30°$. The optimal distance between the fiber tips and top surface, L, is directly related to the required diameter, D, of the acceptance cone at that distance: $L = D / 2 / \tan \theta$. For a square grid with a 10 mm spacing, $D \approx 14$ mm for full coverage, giving an optimal distance $L \approx 12$ mm.

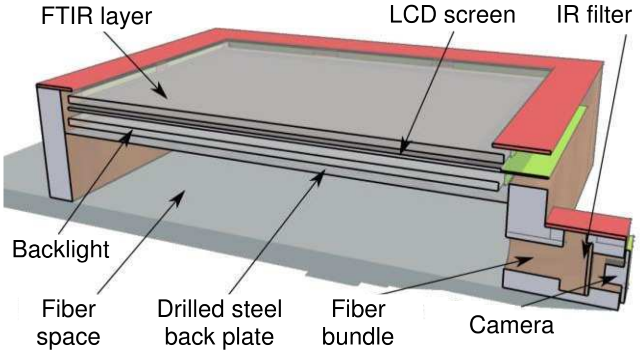


Figure 4. Schematic of the FiberBoard components.

Calibration

The camera images one end of the optical fibers, coupled through free-space. To avoid the difficulties of positioning the fibers to be observed by the camera in an exact spatial arrangement, calibration is required to compute the mapping between the incoherent fibers imaged and the regular matrix at the display. Mapping incoherent fiber optic bundles has formed the subject of several (now expired) patents such as U.S. Patent 4674834 [7], but without previous application to input on display surfaces.

During calibration the display backlight is turned off, an external white light source is directed at the display, and the camera band-pass filter is removed so that it is sensitive to visible light. Calibration software then displays a series of black and white patterns on the LCD layer to shutter off cells over each fiber tip (thereby modulating the received light). In this way we can ensure that light falls on only one column of fibers at a time; this is repeated for each row of fibers. Then, for every fiber position (sensor point), the corresponding row and column luminance images are multiplied to find a map of the image pixels that we can expect to be lit when that sensor point is active.

A coverage map is computed by summing all of the resulting pixel maps. Finally a decoding map is computed. For each pixel we determine the row/column pair that contributes most to the coverage map, and record a normalized proportion of the contribution. This strongly weights contributions from a single sensor point, and ignores pixels whose contribution tends to be from multiple sensor points (e.g. due to reflections seen by the camera). For convenience, the map is stored as an image where the sensor row, column and weighting values are stored in the red, green and blue color channels respectively.

Image processing

Virtual camera software was written to allow existing multi-touch processing software to use the decoded FiberBoard stream as if it was a standard camera device. The capture filter takes the mapping file produced by the calibration procedure, and creates an efficient internal representation of the transformation. Each frame from the attached camera is processed into mapped screen values (summing the weighted luminance values) and the resulting grid is interpolated to yield a higher resolution image using a bicubic filter (see Figure 5). Any fibers found to be missing have a value synthesized by interpolation from neighbors.

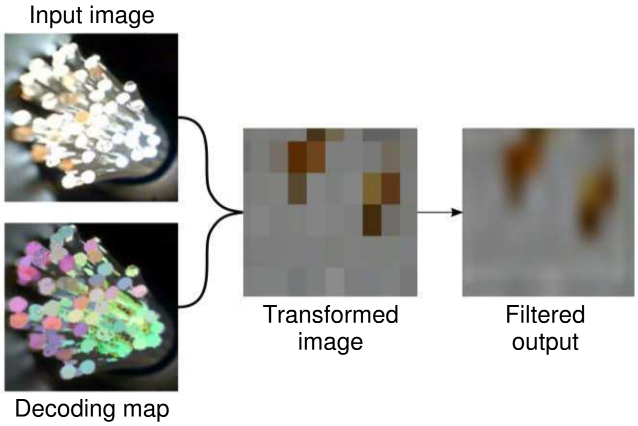
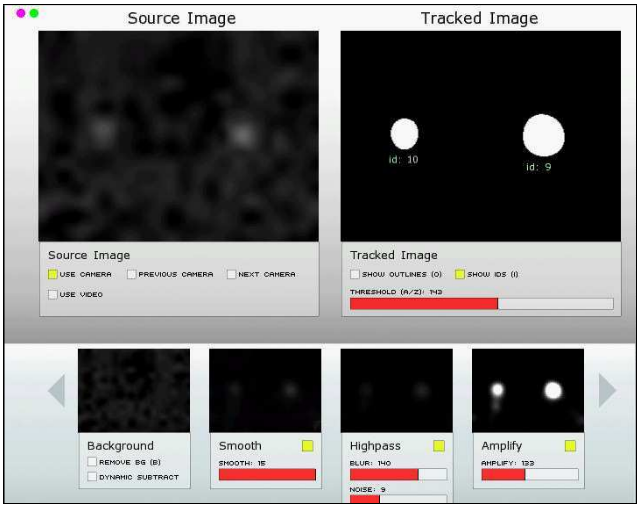


Figure 5. The input image of a fiber bundle is transformed using a decoding map, then filtered to produce the output.

EVALUATION

After calibrating our prototype implementation, existing multi-touch detection and tracking software (*tbeta* from the NUI Group [10]) was used to test the device, Figure 6 shows an example screen. As anticipated, testing revealed that care must be taken not to alter the alignment between the camera and the fiber bundle once calibration has been performed. Rigidly fixing both the camera and fibers to a baseboard avoids this problem. The white backlight proved to be rather faint for general use, but usable in a darkened room. In common with other FTIR implementations, a top-side compliant surface was found to significantly improve the scattering at points of contact and thus the touch sensitivity. Background subtraction (to cope with ambient IR) was also required.



Source Image
☑ USE CAMERA ☐ PREVIOUS CAMERA ☐ NEXT CAMERA
☐ USE VIDEO

Tracked Image
☐ SHOW OUTLINES (O) ☑ SHOW IDS (I)
THRESHOLD (A/Z): 143

Background
☐ REMOVE BG (B)
☐ DYNAMIC SUBTRACT

Smooth ☑
SMOOTH: 15

Highpass ☑
BLUR: 140
NOISE: 9

Amplify ☑
AMPLIFY: 133

Figure 6. Example filtering using *tbeta* software.

Using a 2GHz PC, each frame from a Unibrain Fire-I camera running at a resolution of 640 × 480 (at 30Hz) was processed in approximately 10ms. To determine the functional accuracy of FiberBoard's finger tracking we measured a user's selection of 100 randomly generated touch targets (crosshairs) on our 19" display (resolution 1280 × 1024) for which the mean distance from the target on landing was 15 pixels (std = 8 pixels). Although this is not sufficient to characterize the technical accuracy of our prototype (in that it incorporates a measure of user error and is therefore overly pessimistic) it demonstrates that without further improvement our prototype, with its 10 mm pitch fibers, already has sufficient positional accuracy for on landing selection of sub-finger-width sized targets.

CONCLUSIONS AND FURTHER WORK

FiberBoard is a compact camera-based multi-touch display. It incorporates a novel calibration procedure which uses the output display itself to provide a controllable light mask to resolve the incoherent fiber bundle. Additionally, the virtual camera software allows existing multi-touch software to be used. The array of fibers can also be used to easily construct curved or flexible multi-touch control surfaces. The entirely optical character of the system affords a number of interesting opportunities for input, such as on-surface widgets or active (self-illuminating) markers. Introducing diffuse illumination from lighting fibers behind the display would allow near-surface sensing and recognition of objects and hand pose. Additionally, there is scope for shape and color sensing in the visible spectrum, using a color camera on the fibers synchronized with the LCD screen and pulsed backlight, allowing it to 'see through' the display. The bundle size will scale in proportion to the display area and, where this approaches the limit for a camera, additional cameras could be integrated.

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