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Multi-touch interfaces based on light and optical fibres offer many advantages over alternative technologies. Existing multi-touch devices either use complex custom electronic sensor arrays, or a camera that must be placed relatively distant from the interface. FiberSense is an easily constructed light-sensing multi-touch interface. Using an array of optical fibres, reflected light is channelled to a camera. As the fibres are flexible the camera is free to be positioned so as to allow fibres to be routed anywhere within the interfaces. The resulting effect is a tangible interface that can be produced in any shape, with a complete surface of optical sensors. We describe our prototype, its novel calibration process, and virtual camera software used to easily take advantage of the device.

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FiberSense – Multi-touch Fibre Optic Sensing on Non-Planar Surfaces

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INTRODUCTION AND CONTEXT

Multi-touch interfaces based on light and optical fibres offer many advantages over alternative technologies. Existing multi-touch devices either use complex custom electronic sensor arrays, or a camera that must be placed relatively distant from the interface. FiberSense is an easily constructed light-sensing multi-touch interface. Using an array of optical fibres, reflected light is channelled to a camera. As the fibres are flexible the camera is free to be positioned so as to allow fibres to be routed anywhere within the interfaces. The resulting effect is a tangible interface that can be produced in any shape, with a complete surface of optical sensors. We describe our prototype, its novel calibration process, and virtual camera software used to easily take advantage of the device.

In previous work, we presented FiberBoard [13], a multi-touch display technology based on fibres, but this was primarily developed as a display alternative. With FiberBoard we indicated that it would be possible to use routed fibres as a way of producing non-planar, complex shapes with multi-touch capability. If a display is not required, the technology also allows us to explore colour and depth detection more easily.

RELATED RESEARCH

Multi-touch interfaces offer significant advantages over traditional single touch, for example, allowing concurrent shared use, bimanual interaction and multi-finger gestures. Until recently, multi-touch 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). 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.

Fibre optics have been used to create embedded sensors in the past, primarily concentrating on specific types of sensing, such as temperature [15]. Embedded sensors as a field in their own right are also becoming more commonplace; projects such as work by Gellersen et al. [14] have produced traditional household objects augmented with sensors and data collection technology.

Capacitive sensors have been used for touch sensitive ubiquitous applications for a number of years. Sensors such as Schurter [16] produce are suitable for single touch areas, or a limited number of specific button style regions, but lack the distance sensing capability of optical sensors.

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 areas such as the Apple iPhone, although newer devices, such as N-trig's DuoSense Technology [9], are emerging for larger surfaces. Nevertheless, these technologies lack the capabilities of some light-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 fibre optics to sense multiple touch points. In each element a transmit fibre emits light into a cellular foam layer, and any applied pressure increases the light level reflected to a receiving fibre. Although this allows Kinotex to be placed on non-planar surfaces, it lacks the advantages in our system of being responsive to a variety of wavelengths, allowing colour sensing, and the ability to detect interaction at a distance. This also allows interaction with the interface based on reflectivity, rather than pressure.

We present a method for providing multi-touch sensing using only off-the-shelf components, reducing complexity and cost when compared to solutions requiring bespoke electronics, and allowing custom interface designs, including augmentation of existing objects. (e.g. a dinner plates).

FIBERSENSE

FiberSense works in a similar manner to FiberBoard, but without the requirements of a TFT display, backlight, and FTIR layer. This also removes the need to sense in the IR spectrum, enabling FiberSense to leverage one of a number of different light source implementations.

Light Sources

An ambient source could be used in a well lit environment. This would mean a wide spectra of light would be reflected off objects such as hands which are at a distance from the surface of the interface, whilst items that are in direct contact or very close would produce a shadow compared to the background ambience. If the surface is planar, or a shaped sheet of clear flexible acrylic with no edges more than the critical angle can be manufactured, FTIR can be used. Conversely a source can utilize the existing sensor fibres, transmitting light in the opposite direction, towards the surface of the object, or use an extra set of fibres, solely to transmit the diffuse light.

Object Shape

The array of fibres can also be used to easily construct curved or flexible multi-touch control surfaces. These can be displays, everyday hand-held objects, or objects of infrastructure situated in the environment. Interesting and unique shapes can engage the user, whist the object they tangibly interacting with acts as a digital input device.

In a similar manner to FiberBoard, polymer optical fibres can be placed into holes located on the surface of an object, at approximately 10 mm intervals. As discussed in FiberBoard and reiterated below, 10mm is the largest pitch possible in order to gain full coverage of the surface. The resulting array of fibre is bundled together terminating at the camera, which is placed either within the object it is large enough, or external to the interface.

As an example, 0.5mm diameter polymer fibres have a numerical aperture of 0.5, giving an angle of acceptance, θ, of $\sin^{-1} 0.5 = 30°$. The optimal distance between the fibre tips interaction, L, is directly related to the required diameter, D, of the acceptance cone at that distance: $L = D / 2 / \tan\theta$. For a grid with an approximate spacing of 10 mm, $D \approx 14$ mm for full coverage, giving an optimal distance $L \approx 12$ mm. This means that at distance L, light reception of the fibres is optimal, but that at further distances, the fibres will still have coverage.

Depth and Colour

The ability to detect light levels in numerous spectra allows the creation of interfaces that are colour sensitive. For example, a sensor-augmented object could detect the colour of items placed upon it, colours of user's hands, or coloured indentifying markers. Fibres can detect light reflected at a distance from the surface. Interfaces can be created which can detect distance interactions such as hand waving, objects or hands coming closer to the surface or objects that are changing their orientation on the surface, even if the contact area does not change.

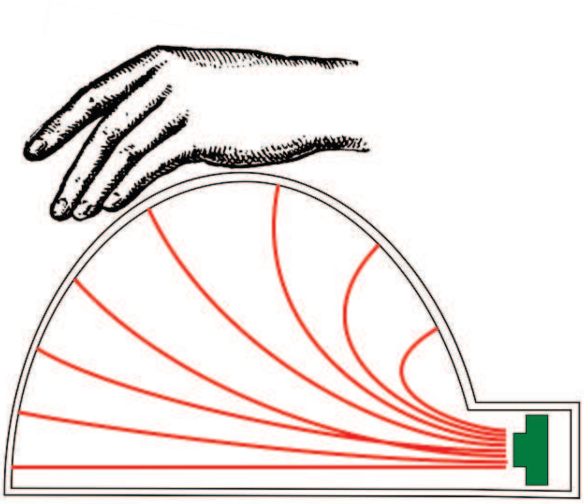

Figure 2. Non-planer object with fibres to the surface, culminating at a camera in the base.

FiberSense uses an automated calibration procedure determined the mapping between terminating fibres and display coordinates. At run-time, a software layer filtered and presents the resulting data as a video capture device. This capability to act as a virtual camera allows us to use existing image processing software to leverage the capabilities of the device.

Calibration

The camera images one end of the optical fibres, coupled through free-space. To avoid the difficulties of positioning the fibres to be observed by the camera in an exact spatial arrangement, calibration is required to compute the mapping between the incoherent fibres imaged and the regular matrix at the display. Mapping incoherent fibre 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 non-planar surfaces.

For calibration of non-planar interfaces, a projector can be used facing the surface of the object, as long as all fibres are in line of sight of the projector. A vertical white line, approximately as wide as the fibre pitch is then projected onto the object at one edge of the projector display, and moved continuously in the horizontal plane, until it reaches the opposite edge. For each pixel in the camera image, the leading and trailing edge of the passing white line can be noted. This process is repeated for the vertical axis. A relative mapping is produced between neighbouring groups of pixels in the camera image, and this can be used to track relative movement across the surface of the object.

Image Processing

Virtual camera software was written to allow existing multi-touch processing software to use the decoded FibreSense 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).

The virtual camera uses the decoding map as a guide to map incoming pixels to object coordinates. As the fibres are not inserted into the object in a regular grid, this mapping takes into account pixels, and therefore fibres that react when a nearby fibre changes, thus we can infer a direction of user interaction with the object from relative changes in pixels.

Once a bright maximum and minimum value of horizontal and vertical has been generated for each of the camera image pixels, when a pixel becomes active in the live camera image, it's associated bounding box, which translates to the expected coverage of a single fibre in the interface, is rendered onto the virtual camera, as an ellipse with a radial alpha gradient from 1 to 0.

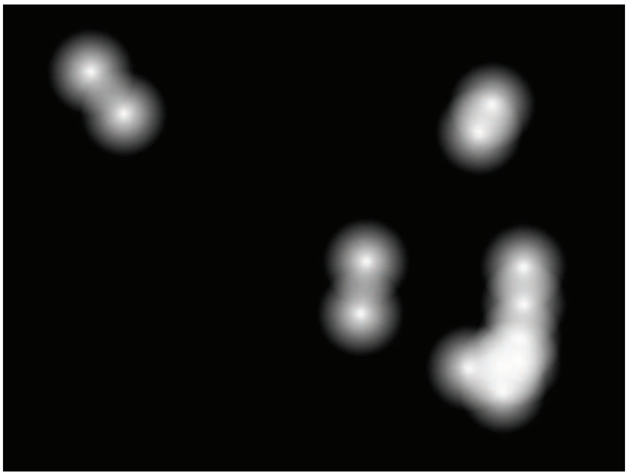

Figure 3. Simulation of resulting virtual camera image with a hand on the surface of an object.

CONCLUSIONS AND FURTHER WORK

FibreSense is a compact camera-based multi-touch interface. It incorporates a novel calibration procedure which uses projected light to provide a controllable mask to resolve the incoherent fibre bundle. 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 as well as colour detection and distance interaction. Due to the optical nature of the interface, fibres used for receiving information in one direction, from the surface of the object, could be used to feedback information to the user. This could be performed by bundling the fibres against a small display, which uses the same input mapping to produce an image which maps to the correct coordinates on the surface of the "display". For example: outlining specific areas on the object that the user can interact with, and providing user touch feedback response. Emission fibres could be interspersed between the sensor fibres in order to provide a response area, or alternatively the same fibres could be used for both by syncing the display with the camera, alternately transmitting and receiving light down the same fibre bundle.

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