Transforming Daily Life Objects into Tactile Interfaces

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Abstract. This article describes a few techniques to transform daily life objects into tactile interfaces, and presents the implementation details for three objects chosen as example: a light globe, a tray and a table. Those techniques can be divided in two main categories, acoustic techniques and computer vision techniques. Acoustic techniques use the vibrations that are produced when touching an object and that are propagating through and on the surface of the object until reaching piezo sensors attached on the surface. The computer vision approach is an extension of the technique used for virtual keyboards, and is based on the detection of fingers intercepting a plane of infrared light projected above the surface by a pair of laser modules. It allows for multi-touch sensing on any flat surfaces.

Keywords: Tangible Acoustic Interfaces, Acoustic Sensors, Computer Vision, Signal Processing, Computer-Human Interfaces.

1 Introduction

In relation with the development of ambient intelligence and pervasive computing, there is a need to create intelligent objects, as well to interact with our surrounding environment in the most natural and intuitive manner. In this context, our interest focused since several years in finding ways to use existing objects as human-computer interfaces. Among the various information that can be retrieved from an object and used in interactive contexts, such as the position, orientation, size, etc, our attention concerned mainly the sense of touch. Our goal was that such objects could be transformed into tactile interfaces with a minimum of modification. This reduces dramatically the scope of suitable sensing methods. Indeed, most touch sensing methods require a sensitive layer to be applied on top of the surface one wants to make tactile (eg. touch screen or touch pad). Moreover such layers require the surface to be flat, while a large number of our surrounding objects are curved. This led us to consider primarily acoustic sensing technologies [6] and, more recently, computer vision technologies. Acoustic sensing has the advantage of integrating smoothly with an object and with a minimum of intervention (only a few sensors to glue on the surface), but is more subject to perturbation due to the manipulation of the object or due to ambient noise. Also, continuous tracking of touch (eg. dragging a finger) is particularly complex and still limited to thin and flat objects. On the other hand, computer vision techniques allow for tracking easily continuous movements but make difficult to detect when touching or not an object. Chapter 2 and 3 will give an overview of the various acoustic and computer vision techniques we have been involved with, either as lead researchers or in collaboration with other research teams in the context of European or national projects. Chapter 4 will provide more details of the practical implementation for three object examples: a light globe, a plastic tray and a table.

2 Acoustic Techniques

Tactile interfaces based on acoustic detection techniques usually refer to the name of Tangible Acoustic Interfaces (TAIs). Tactile information is determined by the mean of the acoustic vibrations that are produced when touching or manipulating an object, either with the hand or with another object (e.g. a stick or a pen). By analyzing those vibrations, it is possible to determine *where* and *how* the object is touched, thus providing a complete description about the tangible interaction.

Many other touch technologies exist but their common disadvantage is either the presence of mechanical or electronic devices at the point(s) of interaction (switches, potentiometers, sensitive layers, force resistive sensors, etc), or the necessity to use a specific kind of material (acrylic pane or semitransparent film) in case of screen based touch interfaces [4], [5]. The major advantage of TAI's is their ability to use any kind of material that can transmit acoustic vibrations, such as metal, wood, plastic and glass, and without the need of fitting the object with intrusive sensors or devices in the area of contact and interaction. This opens the door to transform daily life objects and surfaces into interactive interfaces.

First experiments about TAI's took place at MIT in the 90's [1]. Further researches have demonstrated potential applications for building large-scale interactive displays [2], [3], and for creating new musical interfaces [6], [7]. More recently, a European project of research (TAI-CHI project) has embraced the subject more widely, leading to new technology breakthrough, such as the continuous tracking of fingers touching a surface or the use of 3D objects [8].

There is no single TAI technology, but an ensemble of various techniques and approaches. In the following sections, we will concentrate on two techniques we have been directly involved with and used in two of the examples presented in chapter 4.

2.1 Time Reversal

Time reversal in acoustics is a very efficient solution to focus sound back to its source in a wide range of material including reverberating media [9]. It is based on the principle that the impulse response in a chaotic cavity is unique for a given source location. The method that is employed here is a particular case of the Time Reversal technique and consists in detecting the acoustic waves in solid objects generated by a simple human touch. The detection is a two steps process. The first one is the acquisition of the impulse response: a short pulse is emitted by tapping on the surface of the object, which propagates toward the solid cavity and reflects inside. The reflections are collected by a contact transducer working as a receiver (Figure 1 - Top). The duration of the response depends on the absorption of the material and on the energy radiation property of the cavity.

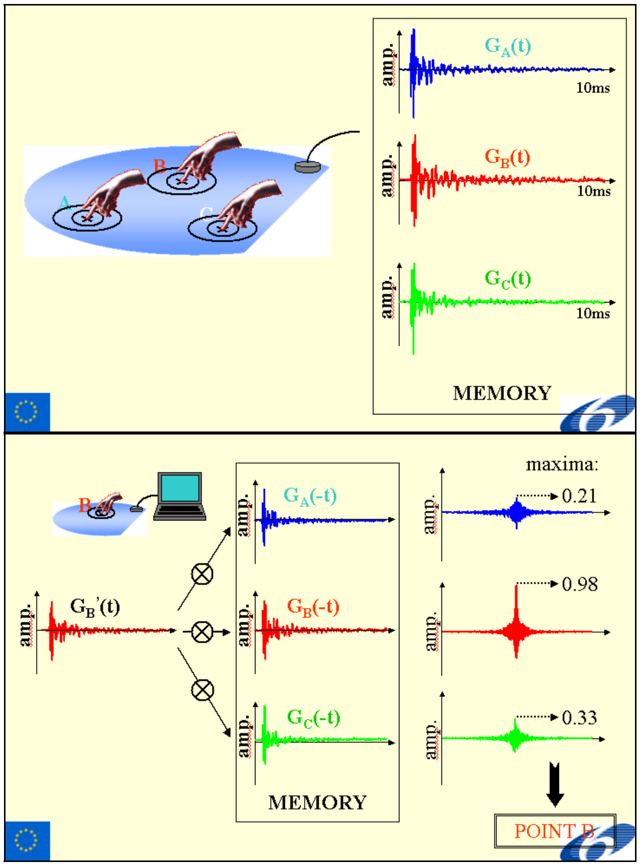


Fig. 1. Training step (*top*) and detection step (*bottom*). Source: *Courtesy of Ros Kiri Ing.*

In the second step (Figure 1 - Bottom), the information related to the source location is extracted by performing a cross-correlation between the stored signals and the live input. The number of possible touch locations at the surface of an object is directly related to the mean wavelength of the detected acoustic wave [10].

2.2 Time Delay of Arrival (TDOA)

TDOA-based locators are all based on a two-step procedure applied on a set of spatially separated microphones. Time delay estimation of the source signals is first performed on pairs of distant sensors (Figure 2). This information is then used for constructing hyperbolic curves that describe for each couple of sensors (the foci of the hyperbola) the location of all points that correspond to the estimated delay. The curves drawn for the different pairs of sensors are then intersected in order to identify the source location [11].

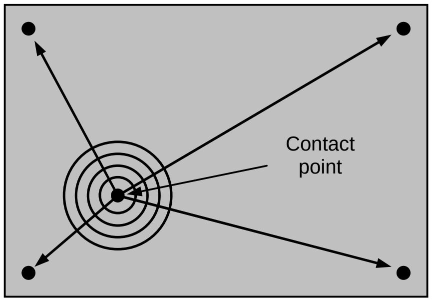


Fig. 2. Basic principle of TDOA estimation.

This constitutes the very simple abstract and geometrical approach to the problem. However, a number of physical phenomena have to be considered in order to make the method reliable. Obviously, the performance of TDOA-based solutions depends very critically on the accuracy and the robustness of the time delay estimation (TDE). One can identify three major problems for TDOA methods for the in-solid case: background noise, reflections (multiple sound propagation paths) and, especially, dispersion. The most crucial problem of in-solid localization is given by the phase velocity dispersion occurring with in-solid wave propagation [12]. The main effect of dispersion is that acoustic waves change their shape in the time domain while they propagate, and therefore the slope of the impulse corresponding to the tactile interaction is modified. The TDOA method is more advantageously used with flat surfaces. However, the same principle can also be applied to curved surfaces, with some additional effort for calculating the hyperbolic curves in the three dimensional space.

2.3 Modular Hardware Platform

In order to create embedded stand-alone applications, that is without using a PC, we are using a modular hardware platform named ‘Presto Kit’ that we are constantly expanding through the years and that serves as rapid prototyping kit for many of our projects. The modular architecture of the platform is basically composed of four different types of boards that can be combined together:

- I/O (eg. audio, video, sensors, LEDs, relays)
- Processing (fixed point, floating point DSP’s)
- Communication (eg. Ethernet, FireWire, USB, Wireless, MIDI)
- Integrated (microcontroller + I/O + Com.)

Several options exist or are under development for each kind of boards, allowing users to choose the right combination for each application. Boards are stacked one above the other, thanks to a common bus for data transfer that is crossing them vertically (Figure 8).

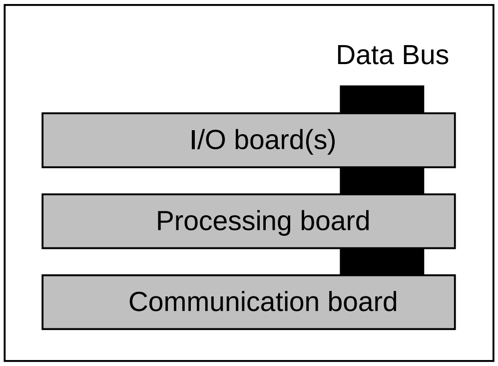


Fig. 8. Modular architecture of the Presto Kit.

In those examples with Tangible Acoustic Interfaces, the configuration is composed of a specifically designed preamp board for acoustic sensors (8 channels), a high sampling rate acquisition board (up to 384 KHz), a digital signal processing (DSP) board, and a MIDI board for connecting to a sound module (Percussion Tray), or a relay board for controlling the LED's (Light Globe). During the development phase of algorithms, we were using a FireWire communication board in order to stream signals into Matlab application. Figure 9 shows the first three boards.

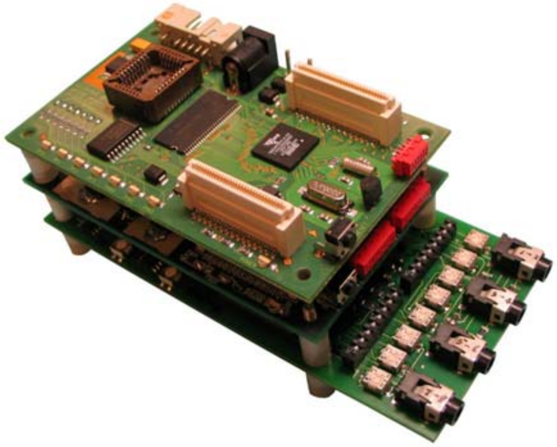


Fig. 9. Presto Kit with signal conditioning board for acoustic sensors (bottom), high-speed ADC board (middle) and processing board with BlackFin DSP.

Depending on the need, the system can run with uClinux operating system, or with lighter ZottaOS.

3 Computer Vision Approach

Multi-touch screens and surfaces are becoming more and more popular. However, most of the available technologies and approaches only work in specific conditions and are not suitable for ordinary surfaces. For instance, some sensing systems are embedded into the surface [13], [18], [24], while others are specific to screens, either as an overlay above the screen (iPhone, iPod Touch), or as a vision system placed behind a rear projected diffusion screen [4], [5], [23], [28].

Solutions exist to track multiple fingers on a generic surface [14], [15], [22], but they are not suitable for detecting individual contact points, that is, if fingers are touching or not the surface. True detection of touch can be achieved roughly using stereoscopy [16], [21], or more precisely with four cameras placed in the corners of the interactive area [17], [27]. It can also be achieved with a single camera by analyzing the shadow of the fingers [20], or by watching fingers intercepting a plane of infrared light projected above the surface [19]. Virtual Keyboards currently on the market [25], [26] are based on this approach, which has the advantage of requiring less computational power than the other ones. However, those devices do not compute true coordinates of touch and their interactive area is limited to keyboard size. We have adapted this method to be compatible with larger surfaces, and combined it with acoustic onset detection in order to get precise timing information. In addition to fingers, our system can detect oblong objects striking the surface, like sticks and pencils, and it is also suitable to measures the intensity of taps or impacts, allowing to perform the interface both with percussive and touch gestures.

3.1 Multi-touch Detection

At first, a plane of infrared light is created about 1 cm above the surface by using two laser modules equipped with ‘line generator’ lenses. When fingers or other objects are intersecting the plane, the reflected light is detected by an infrared camera as brighter spots in the image (Figure 3).

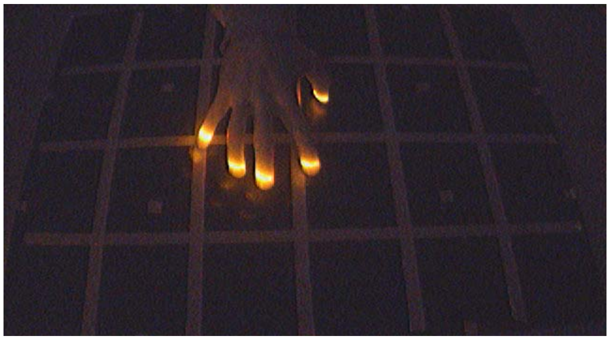


Fig. 3. Image seen by the camera. Visible light is filtered out using a 800nm pass filter.

Simple blob tracking is performed digitally using high-pass filtering, in order to get the finger positions in the image space. Finally, the image positions are converted to the physical space using bi-linear interpolation techniques, after a calibration procedure using a grid of known points.

4 Implementation Examples

4.1 Light Globe

This demonstrator is based on the time reversal technique presented on Chapter 2.1, which relies on the recognition of acoustic signatures. The advantage of this principle is that objects of virtually any shape - flat, non-flat, or irregular - can be transformed into input interfaces with a finite number of interaction points. Usually, one sensor is sufficient, as long as it can be fixed away from a symmetry axis. In this case, any point on the object will have a unique acoustic signature recorded at the sensor level. However, with circular, cylindrical, and spherical objects, there is an infinity of symmetry axis, which means that wherever the sensor is fixed, there will always be two points with the same acoustic response. In order to avoid this, it is necessary to fix two sensors, taking care that both are not on the same symmetry axis. Therefore, in this example, two sensors were used, and placed inside the base of the light globe.

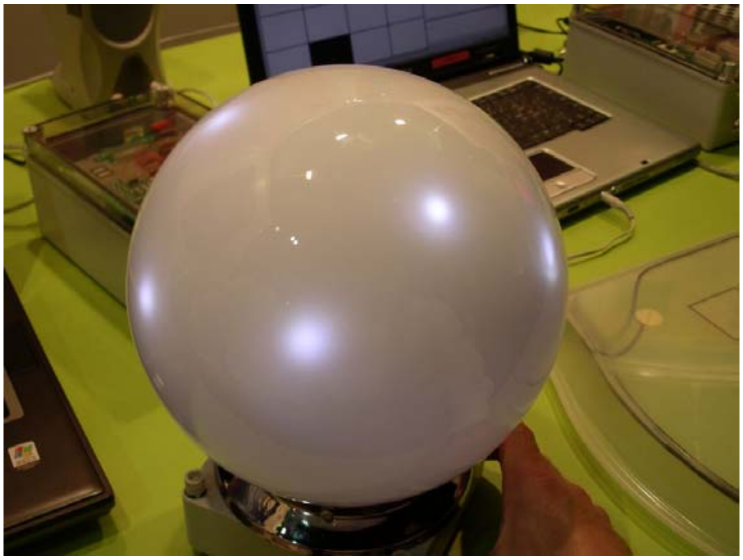


Fig. 4. The light globe with LED's placed under the surface and indicating the position of sensitive spots.

As explained in Chapter 2.1, the tactile detection based on Time Reversal is a two-steps procedure, with a training phase, and a running phase. During the training phase (or learning phase), users have to tap with their nail (or another hard object like a ball pen) a few times in order for the system to record the specific acoustic signature. It is thus necessary to have some kind of visual feedback in order to recognize those points. In this demo, the visual feedback is given by a certain number of LED's placed randomly behind the surface of the globe. During the training phase, all LED's are activated. For the running phase, two interactive scenarios were implemented. In the first one, the different spots would act as simple switches. Tapping on a colored spot would simply switch off the corresponding LED. Once all LED's are off, the cycle starts again. For the second scenario, a small game was implemented. LED's are flashing one after the other randomly and users have to 'catch' them by tapping on the active spot before it is turned off again. When successful, the LED remains activated until all others are caught as well. Then a new cycle starts again but faster, that is with less time between two flashing LED's.

4.2 Percussion Tray

The percussion tray demo is based on the TDOA method presented in Chapter 2.2. Four piezoelectric sensors are placed close to the corners of a plastic tray and connected to an electronic device (see section 4.4 for a more detailed description), for calculating the positions of fingers or sticks hitting the tray's bottom (Figure 5).

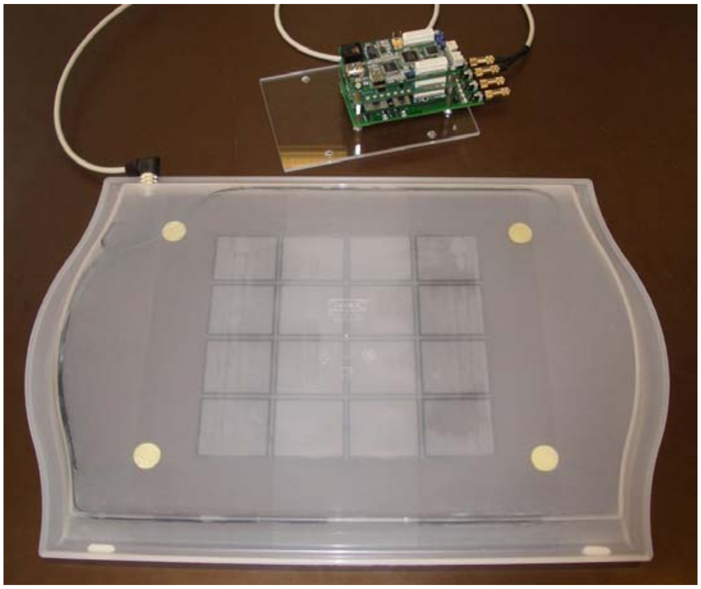


Fig. 5. The Percussion Tray with four acoustic sensors connected to the processing module.

In this example, the interface is used as a drum pad. The electronic device is connected via MIDI (Musical Instrument Digital Interface) to an external drum module, where sampled sounds are triggered according to the hit location. For this purpose, a tracing paper with a printed grid of 16 pads is glued on the tray to have a visual reference. The tray is used up side down, and since it is slightly transparent, the tracing paper is visible from the opposite face.

An important feature for such musical application is that there is no noticeable delay in the sonic response when tapping on the tray. Also it is possible to retrigger sounds very quickly, like rolls, up to 20 times per second, with a precision of 1 cm. Previous experiences with tap positions calculated on a personal computer showed it was not possible to reach such performances because of the delay required for signal transmission.

4.3 Multi-touch Table

Figure 6 gives an overview of the setup. The system is comprised of an infrared camera placed above the upper edge of the surface, and two laser modules placed in the corners of the surface one wants to make touch sensitive. The laser modules also contain piezoelectric sensors for sensing the intensity and nature of impacts. They are connected to an electronic board for controlling the power of lasers and processing

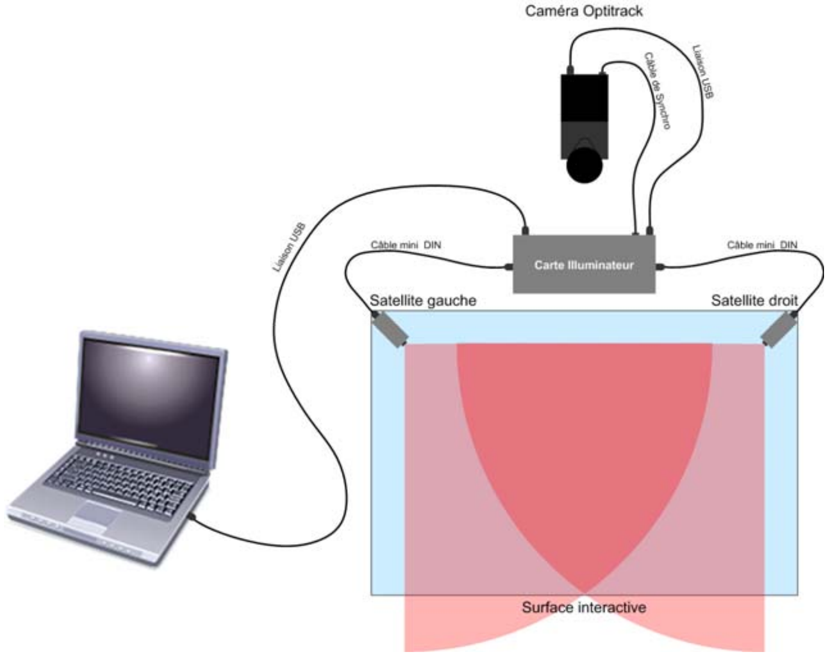


Fig. 6. Overview of the multi-touch setup, with laser modules, electronic board and IR camera.

sensor information. The chosen camera is an OptiTrack Slim:V100 [29], which features embedded blob tracking at 100 fps, allowing for much faster performances and reduced CPU usage than using a normal camera. Also, this camera provides a sync link, which allows for synchronizing the lasers with the shutter of the camera, resulting in an increased signal to noise ratio. Figure 7 shows the system in use, with a simple wood board. The obtained precision is of about 3mm. An interesting possibility, for instance, is to create tool bars or control menus simply by drawing them on a piece of paper and tape them on the surface, like shown on Figure 7.

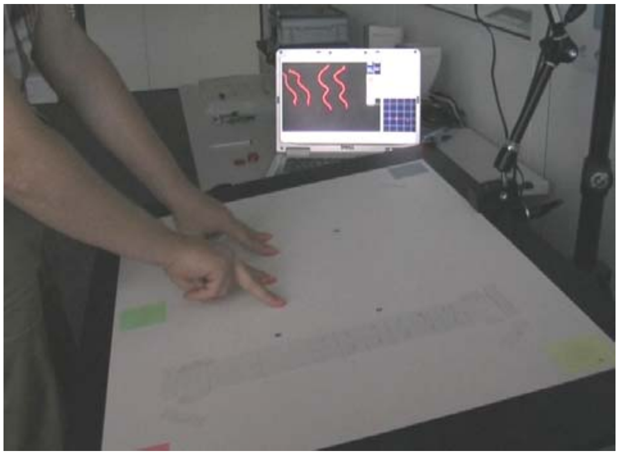
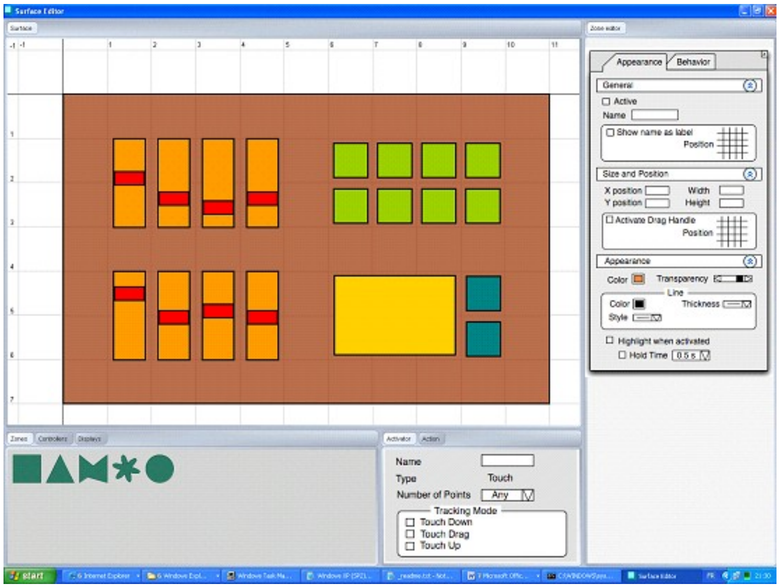


Fig. 7. Simple wood board transformed into multi-touch input interface. A menu with various functions is drawn on a piece of paper on the right side of the table, and used in conjunction with a simple drawing application.

4.4 Surface Editor

The Surface Editor is a graphical software tool that we developed in order to facilitate the creation of interactive scenarios and prototype applications. User interfaces are created easily by placing mapping components on the editor’s screen, which represents the surface of the interface, and adjusting their parameters. Mapping components are defining the relationship between physical actions (input gestures) and programmed actions (output actions). Each mapping component is implemented in the form of a plug-in and can therefore be custom designed for each particular application. Typical mapping components include GUI elements such as knobs, faders, buttons, etc. The editor is also providing a visual feedback to users, which can optionally be projected on the interface. Figure 8 is showing an application example of the Surface Editor for creating reconfigurable musical controllers. Each component is configured for sending MIDI events to a synthesizer or sound module connected to the computer.



Appearance | Behavior

General

☐ Active

Name

☐ Show name as label

Position

Size and Position

X position

Width

Y position

Height

☐ Activate Drag Handle

Position

Appearance

Color

Transparency

Line

Color

Thickness

Style

☐ Highlight when activated

☐ Hold Time 0.5 s

Name

Type Touch

Number of Points Any

Tracking Mode

☐ Touch Down

☐ Touch Drag

☐ Touch Up

Fig. 8. The Surface Editor with specific mapping components dedicated to create virtual musical controllers.

5 Conclusion

We presented several techniques and tools for transforming daily life objects into tactile interfaces. Each of the methods and approaches has their own advantages and disadvantages. Application developers have to chose which one is the best appropriate for a particular application, in particular in relation with the context of use. For instance, acoustic techniques have an advantage in term of integration for public installations, since all sensing part can be hidden behind the surface or inside the object. On the other hand, the computer vision technique presented here allows for more sophisticated interaction, with continuous sensing of multiple touch points, but can be perturbed by direct sun light. No one technique is better than another and that's why we continue to develop both the acoustic and computer vision approaches, in order to face various applications contexts.

It must also be said that most techniques and prototypes presented here were initially developed with the intension to create new musical instruments. The fundamental statement was to be able to use vibrating elements as input interfaces. Therefore, it was necessary to find non-intrusive touch technologies that allow for using existing objects and structures without modifying them. By extension, this allowed for using daily life objects, opening the way for many other applications, like smarts objects and context-aware environments, and more generally for creating more natural and transparent user interfaces. Traditional sensing techniques have the disadvantage of requiring mechanical or electronic devices at the point of interaction with the interface (switches, potentiometers, sensitive layers, force resistive sensors, RFID, etc). This increases manufacturing costs and limits the interaction to predetermined points or surfaces fitted with the appropriate sensing technology. The methods presented here suppress the need for intrusive sensors or devices in the area of contact and interaction. Instead, the entire object becomes like a giant sensor, allowing for more extended interaction areas, and thus providing a possible path towards the creation of ‘smart surroundings’.

More information on the recent developments on www.future-instruments.net.

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