A Customizable Sensate Surface for Music Control

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ABSTRACT
This paper describes a novel music control sensate surface, which enables integration between any musical instruments with a versatile, customizable, and essentially cost-effective user interface. This sensate surface is based on conductive inkjet printing technology which allows capacitive sensor electrodes and connections between electronics components to be printed onto a large roll of flexible substrate that is unrestricted in length. The high dynamic range capacitive sensing electrodes can not only infer touch, but near-range, non-contact gestural nuance in a music performance. With this sensate surface, users can “cut” out their desired shapes, “paste” the number of inputs, and customize their controller interface, which can then send signals wirelessly to effects or software synthesizers. We seek to find a solution for integrating the form factor of traditional music controllers seamlessly on top of one’s music instrument and meanwhile adding expressiveness to the music performance by sensing and incorporating movements and gestures to manipulate the musical output. We present an example of implementation on an electric ukulele and provide several design examples to demonstrate the versatile capabilities of this system.

Keywords
Sensate surface, music controller skin, customizable controller surface, flexible electronics

1. INTRODUCTION
For years, researchers have been working on exploiting standard input devices to develop new electronic music controllers with intuitive interfaces and ways to enable people to play synthesizers [1-2]. Controlling sound with more precision but less complexity has long held the interests of musicians especially in live performances. A common problem among many music controllers is the lack of interface that is specifically designed for integrating and simplifying different interfaces, especially with traditional instruments. Imagine if you have an expensive handcrafted violin, you would never want to change the shape nor add knobs and switches on it.

One of the major challenges for an understaffed live performance is to multitask on stage between controlling switches, knobs, effects, pedals and, at the same time, focus on musical expression.

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This project seeks to provide a customizable wireless music controller surface that can be easily adapted by musicians and seamlessly integrated with any existing music instrument.

Our goal is to create a skin-like sensate surface which allows users to build their desired controller without changing the geometry of their instruments. We believe that this approach is an efficient and cost-effective method to create a user interface for music since our platform is highly adaptive and can be custom-designed by users.

To achieve this goal, we explore the use of a recently available technology, conductive inkjet printing, as an enabler for building low-cost sensate surfaces. To illustrate this, we used an electric ukulele as example and showed circuit implementation and pattern design tailored for specific musical gestures. We printed different designs and explored how the addition of integrated instrument effect controller could benefit a live performance and how it is possible to have an electronic surface that can add something to the aesthetic to a musical instrument. Besides sending basic control signals, we also explore the possibilities of embedding sensors in areas where extended hand gestures during a performance can be detected and use that information to contribute expressiveness to the musical outputs.

2. MOTIVATION AND RELATED WORK
Performing live on stage and simultaneously using various controllers has never been an easy task. Although the days of manipulation of knobs and switches from rack of synthesizers are now replaced by touchscreens on tablets and laptops, it is still not easy to switch back and forth between a traditional instrument and a software interface. It can be difficult to modify an existing instrument since the shape design is commonly optimized for playing. Our motivation is to create a sensate “skin” for extra control inputs which allow musicians to implement their desired sensing components on the surface of their instruments and replace extra movements with additional control inputs (figure 1).

Previous work related to adding extra control through embedding sensing components into musical instruments for alternative control such as the Starr Labs “ZTAR” [3], a guitar-like digital instrument with a touch sensitive fingerboard, string triggers, hotkeys and a joystick, Stepp’s DG-1 analog guitar synthesizer [4], Donald Buchla’s Thunder percussion controller, which replaced keyboards with flat pressure and position-sensitive capacitive touch plates [5]. These examples demonstrate the potential of extending the possibilities in music expression through adding additional tactile sensing components and create new ways to interact with digital control. However, there is no existing option for an average user to implement sensing capabilities besides purchasing control surfaces like a Korg's Kaossilator as a building block.

We would like to create a system that allows users to modify their instrument in an elegant way without changing the original shape and design of their instruments. Inspired by the Chameleon Guitar [6], a hybrid acoustic and digital instrument with a replaceable acoustic resonator which preserves the traditional acoustic values while capable of digital manipulation abilities, we attempt to create a digital interface that preserves the physical shape and properties of an instrument.

In this paper, we use an electric ukulele (Eleuke SC-100) as an example to demonstrate the possibility of adding more controlling power to a small surface and the potential impact on future live performances. Figure 1 shows one of the implementations of our design.

Figure 1. Implementation of our system[1] with additional control inputs to send the most commonly used commands and reduce movement path during a live performance.

Previous works on building pressure sensitive surfaces with printed FSRs and capacitive sensing for generic surface for musical expression include Koehly et al. [7], Jones et al. [8] and Freed [14]. These novel sensing surfaces were designed as a new instrument for playing music. Our design, however, is not purposed for serving as a standalone musical instrument. Our surface is built specifically for increasing the expressiveness of an existing instrument.

Our motivation and major contribution for the field of music controllers and interfaces can be summarized as follows:

1. Create a low-cost and customizable capacitive sensing based hardware toolkit for music user interface development.
2. Dynamic range detection from capacitive sensing can infer not only touch, but near-range gestural nuance.
3. Provide working examples of the combination graphic design and circuit design which enables a physical manipulation of software interfaces.

3. SYSTEM OVERVIEW

We built a sensate surface controller prototype and provided three design examples on an electric ukulele. The surface detects gestures and touch and transmits its intensity and location wirelessly via Bluetooth to a software host on a computer, which then converts the signal into MIDI messages. These MIDI messages were then mapped, based on the location of the gesture, to control signals such as tap tempo, pitch, distortion or simpler commands like volume change or record/stop.

3.1 Design and Functionality

Our design principal is to embed extra control input ability in spaces that are normally too small or not suitable for implementing extra components such as knobs and sliders. [1]Figure 2(a) is an illustration of different potential areas for adding control inputs on our example instrument. Based on the gesture of playing this instrument, the three zones are mapped to different functionalities in our design. Figure 2(b) shows how extra control inputs could be implemented in a traditional design and we demonstrate the same functionality could be achieved with an aesthetic or decorative sensate surface input in figure 2(c).

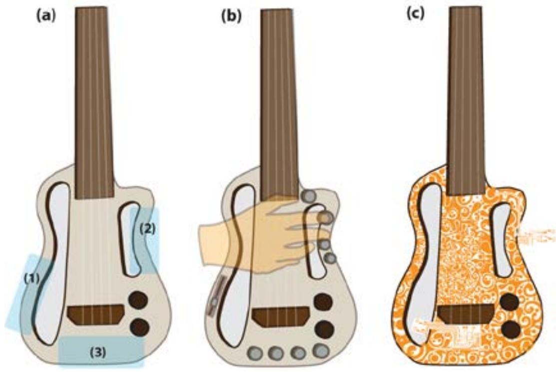

Figure 2. (a) Potential spaces (blue zones) for extra control inputs. (b) Illustration of traditional implementation of additional control inputs (c) Control surface design pattern with the same effect as (b) without physically change the original instrument.

3.2 Hardware Design

There are two parts in the hardware design. First, a flexible sensate surface printed with sensor patterns and limited components for capacitive sensing. And second, a PCB for data processing and wireless communication.

Our prototype sensate surface is based on printing copper patterns onto a thin plastic substrate using conductive inkjet printing technology. With this technology, it is possible for us to print complex conductive patterns for electromagnetic field sensing [9-10]. The total cost for our design per ukulele is less than 10 US dollars (~$7 for the printing and ~$3 for components). The sensing method is capacitive sensing, which relies on Loading Mode [11-12] – measuring the capacitance change between a human hand and a metal electrode. By measuring the time between several charge and discharge cycles, the distance between a user's finger from the surface can be measured. While it is possible to attach surface-mount components directly to the surface with low temperature solder or conductive adhesive, this process takes more time and the mechanical connection is not as strong as regular solder joints. Therefore, we minimized the components required for the flexible surface and only placed the critical parts, which are the capacitive sensing circuit and connections for communication with the microcontroller.

Figure 3 (a) shows the printout of our example designs and figure 3(b) shows the surface mount component attached to the flexible surface. We implemented CY8C20x CapSense capacitive sensing IC from Cypress semiconductor, which is capable of supporting up to 28 CapSense I/O touch channels with two wire communication protocol and 16 bits of resolution. The device address of CY8C20 can be changed manually, which allows multiple CapSense slave devices on the same bus. The device uses a seven bit addressing protocol

[1] Pattern design adapted from the artwork, Soulgazer, of Evgeny Kiselev

where the last bit in a byte indicates read or write. This means there can be 2^7 addresses on the same two wire bus line – a total of 7168 (28 times 256) inputs, if designed properly.

Also, this device supports two different filtering methods to reduce noise from different sources - the DTS filter to discard samples acquired while data communication takes place, and the averaging filter to improve CapSense system noise immunity.

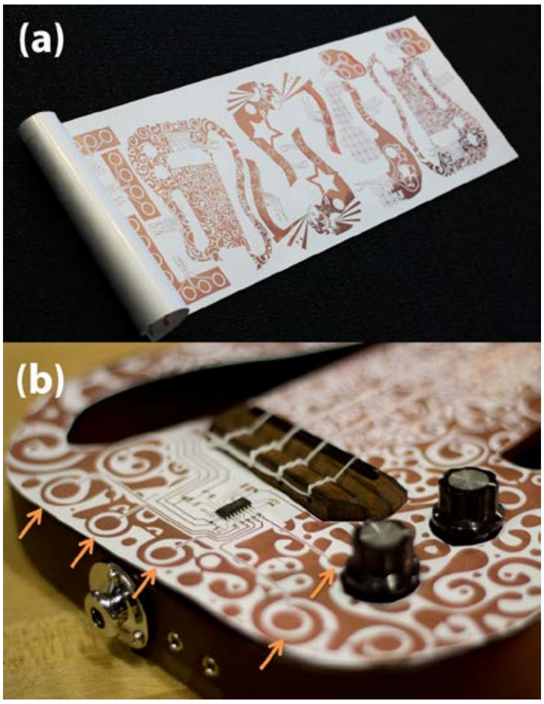

Figure 3. (a) Printout of our example designs. (b) Capacitive sensing buttons (indicated by orange arrows) and associated circuit with surface mount components (CY8C20) attached to the flexible surface.

For the PCB part, we used an off-the-shelf ATmega 328P (http://www.atmel.com/) development board with 8 MHz external oscillator and Bluetooth radio chip (RN-42) from Roving Networks (http://www.rovingnetworks.com/). We wanted to design a modular and highly adaptive system that allows the sensate surface customization to be versatile yet intuitive for novices with minimum wiring. Therefore, we selected sensor ICs that support two-wire communication where only 4 connections were needed between the PCB and the flexible surface – power, ground, data (SDA) and clock (SCK). Once the capacitive sensors are triggered by touch or movements above the surface, data is transmitted to the host microcontroller, then processed locally and wirelessly transmitted to software which converts sensor information into MIDI signals according to the mapping design.

In our study, we used a MIDI library from Processing.org and sent MIDI commands to Propellerhead Reason 6.0, a digital music synthesizer platform, to generate sound and create a mapping to trigger effects and change the pitch and modulation of our instrumental input.

4. MAPPING STRATEGIES

The mapping strategies depend highly on the application and physical construction of specific instrument and the location where sensor units are placed. Here, we discuss mapping strategies both from the physical and signal point of view. Again, we used a ukulele as example to explain the relationship of sensor placement, hand gestures, and output mapping.

4.1 Physical Mapping

Our mapping strategies are designed for demoing the variety of sound effects that can be achieved via an on-body control surfaces for a stringed instrument such as a guitar or an ukulele. The pattern construction was built around three zones that have different impacts on gestures, such as finger picking or strumming. These three areas are trigger area, movement area and command area (figure 4).

The trigger area includes the most commonly covered right hand movement - ranging from strumming patterns by rhythm guitarist to fingerpicking from playing bluegrass-style banjo music (where clips are wore on one's thumb, middle and index fingers and one or two fingers rest on the instrument). In this area, the sensor inputs are mapped to pitch and modulation control so the player can either change the sound or add modulation while plucking the strings. The second area is the trigger area. During a finger style guitar performance, players pluck the strings with their fingertips, add fingernails and rest their thumbs on the side. We use this area as the trigger area, where precise controls are made to trigger loops, instruments or pre-composed tracks. The last area is the command area, which is less likely to be triggered accidentally during a performance. In this area, we place inputs that have critical functions such as "play", "record", "stop".

In the mapping design, we also considered the possibility of detecting extended hand gestures during a performance and how to use that information to add expressiveness to the musical outputs. One of the advantages of capacitive sensing over pressure sensing is that we can detect proximity. Therefore, it is possible to map gestures, such as strumming, to beat generation.

In our first prototype, we did not design patterns specifically for sliders. Instead, we post-processed the data on the software end and were able to map a continuous motion trajectory from the button inputs to a slider motion. Besides sliders and buttons, inputs for continuous velocity control are also very important for musical expression. Therefore, a layer of silicone on top of copper pads was included in our design as a way to generate continuous velocity control. The distance between one's finger and the copper pad (the distance between two conductors) is controlled by force applied on the silicone.

This sensate surface can be applied to essentially any instrument, and our mappings are designed only for demoing one of the many possibilities.

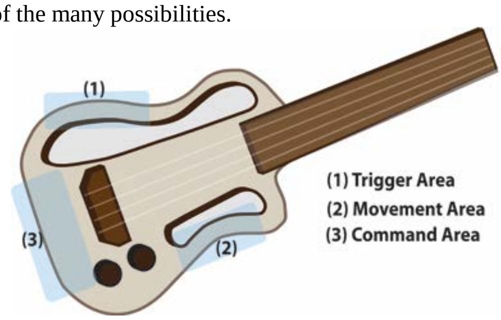

Figure 4. Potential mapping on a plucked string instrument based on gestures such as finger tapping, picking and strumming.

5. CUSTOMIZATION

Since the process of printing flexible circuit is similar to using a printer, it is possible to draw out the circuit the same way as drawing with any graphic editing tool that allows you to export a bitmap file. We invited three users to design their control surface with the same process of creating an artwork with Adobe illustrator. We provided the design guidelines and several circuit layout images required to process capacitive sensing signals, control LEDs for indications and to connect to the PCB for data transmission. Our hope was to not only enable people to implement a sensor circuit on their instrument, but also design an artwork that is aesthetically appealing. Figure 5 shows the three different designs. Figure 5(a) is a design with whole body coverage and has sensor components covering all three interaction zones. Figure 5(b) and (c) are designs for partial coverage - (b) includes only the trigger and the movement area while (c) covers the command and trigger area. Two of the designs, (a) and (c), placed the circuit on top of the surface while (b) hid all the wiring and components in the back. The advantage of having traces close the pads reduce the risk of broken connection due to folding, especially when some of the stress points were designed very close to surface mount components which can easily cause connection issues. The disadvantage was having less space for touch inputs.

The combination of graphic design and circuit design creates a new art form itself that allows each sensate “skin” controller to represent the music genre this controller is mapped to. We envision a musician with a wardrobe of different surface controllers that are interchangeable similar to switching between effects or synthesizer racks.

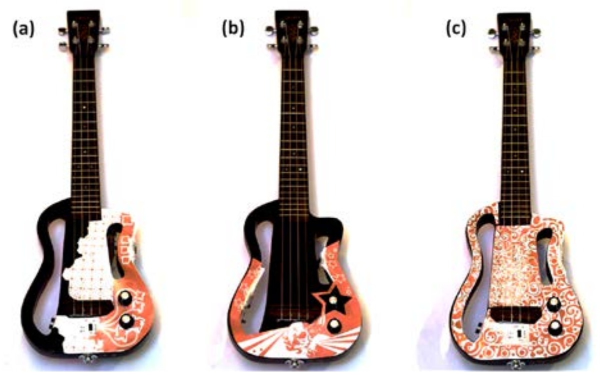

Figure 5. Three example designs for different coverage and input locations.

We realize that the complexity of drawing, mapping and routing can be difficult and time-consuming. Therefore, our future work is to develop a software toolbox for optimizing the sensor design (such as error checking for reducing signal to noise ratio or short circuit) which allows any musician to draw out the shape and customize their desired patterns for their own control surfaces. The design should be able to be integrated with anything in one’s environment or on top of any object with minimized signal to noise ratio.

6. CONCLUSIONS AND FUTURE WORK

In this paper, we presented a novel music control sensate surface based on conductive inkjet printing technology which enables customizable integration between any musical instrument with a versatile and cost-effective user interface. We provided design examples and corresponding physical mapping strategies for different finger techniques for plucked string instruments. Our main interest lies in developing a system for producing new forms of performances and instruments through empowering musicians with the ability to improve, modify, and extend the capabilities of traditional instruments.

Future work includes creating more sophisticated toolkits with multiple sensing modalities and better capacitive sensing capabilities (such as sensing for longer range). We also plan on developing a software toolbox which will allow users to drag and drop sensor inputs and create the link to MIDI signals for software mapping and synthesizer manipulation. In addition to music applications, we are interested in applying this technology to other fields as well. Potential areas include Natural User Interface design, interactive media and smart architecture.

7. ACKNOWLEDGMENTS

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