Seaboard: a new piano keyboard-related interface combining discrete and continuous control

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ABSTRACT

This paper introduces the Seaboard, a new tangible musical instrument which aims to provide musicians with significant capability to manipulate sound in real-time in a musically intuitive way. It introduces the core design features which make the Seaboard unique, and describes the motivation and rationale behind the design. The fundamental approach to dealing with problems associated with discrete and continuous inputs is summarized.

Keywords

Piano keyboard-related interface, continuous and discrete control, haptic feedback, Human-Computer Interaction (HCI)

1. INTRODUCTION

The Seaboard is a new musical instrument which enables real-time continuous polyphonic control of pitch, amplitude and timbral variation. This novel tangible interface was invented, designed and developed by Roland Lamb, in the context of his studies in the Design Products Department at the Royal College of Art. During the software development stage of the third prototype, Andrew Robertson joined the project to assist with the software design and implementation. The initial motivation for the Seaboard came from the desire to augment the capabilities of the piano and, in particular, to combine the capacity for real-time polyphonic expression with the ability to bend the pitch of every note independently.

Keyboard controllers have been designed with the acoustic piano keyboard as the interface paradigm on which they are based. Many electronic keyboards have pitch wheels which add pitch-bending capabilities. Pitch wheels, however, are of limited use for serious musical performance and do not enable real-time note-by-note polyphonic pitch bending. Piano-like polyphonic pitch-bending interfaces do exist, most notably the Haken Continuum Fingerboard [3], which allows for multiple pitch bends at the same time and also registers the vertical location of an input and its downward pressure. However, the Fingerboard provides the musician with a limited amount of tactile information about finger location, and thus (especially when playing polyphonically) if software correction is not utilized to force tones to snap to the tuning of the twelve-tone scale, then either visual confirmation of each note is necessary or a vibrato technique must be employed. The Rolky Asproyd, designed by Eric Johnstone [5], is a poly-touch controller that makes use of illumination to detect the position of several fingers on a transparent surface, thereby providing control over each note in the chord. Nevertheless, no instrument based on the piano layout has previously provided a musically intuitive way of providing polyphonic pitch-bending capacity while also enabling effective tuned playing.

Figure 1: The Seaboard surface

2. DESIGN

At the broadest level of description, one can identify two ways of making music: traditional musical instruments on the one hand and modular technology—various kinds of synthesizers, sampling, and digital effects—on the other. Traditional instruments provide great depth, refinement, and performative possibilities, but more limited scope, whereas modular technology has enormous scope but is often poorly integrated and difficult to use in real time.

The goal of the Seaboard design process, like that of many new digital interfaces and instruments, has been to deliver an integrated music-creation device which combines the best of both of these approaches. Our aim has been to make use of both the more fundamental intuitive associations (i.e. pressure relates to volume) which enable the learning process and the connection between musician and instrument, and the possibility of taking advantage of more arbitrary

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but nevertheless established intuitions in considering key design choices.

In concrete terms, the Seaboard interface takes the basic design layout of the piano keyboard and refashions it with a new surface shape and a new material. The discrete keys of the piano have been physically re-imagined as a single, continuous, non-flat surface, where the relatively raised and recessed areas of the surface correspond with the centers of the white and black keys (See Figure 1). The top of the interface is made of a soft silicone, which rests upon an array of force sensing resistor (FSR) sensors. A software algorithm measures the variations in pressure and location of the pressure peaks in the sensor array, thereby forming a representation of which notes the user is playing on the Seaboard, and sends out the corresponding MIDI or OSC messages.

In addressing the question of how to make an effective tactile instrument that would allow for a wide range of sound and music creation possibilities, and yet remains intuitive, the piano keyboard layout was a good place to start. The visual and logical layout is one of the reasons for the success of the piano, especially as a general interface for musicians to learn basic music theory.

Another reason to adopt the piano keyboard as a starting place lay in its familiarity. New musical instruments and interfaces are often proposed, especially in the digital age, yet comparatively few become established and widely accepted. One reason has to do with the enormous amount of energy that one has to devote to learn a new instrument well, and unless an instrument garners a small community of musicians who play it very well, it is difficult for it to find a path to wider acceptance. Dobrian and Koppelman [?] point out that for a new interface to facilitate musical expression, not only must the interface be well designed, for example with respect to mapping gesture to sound parameters, but players must also take the time to master the interface in order to achieve the level of virtuosity we associate with traditional instruments.

In addition to designing the Seaboard in such a way that a musician could transfer keyboard skill and understanding, a strong emphasis was placed on making the new capabilities one that could be learned and endlessly refined through practice, rather than providing easy software workarounds. Highly skilled manipulation of complex sound variables and attributes depends on practice, and the reason practice is effective in these areas is that one can train one's muscular memory to repeat certain delimited tasks without conscious direction or control. We observed that in order for such training to be possible though, there are three requirements: a) the activity must not inherently require visual confirmation and direction (activities that require visual confirmation, like shooting a target, can of course also be practiced, but involve a different form of practice involving hand/eye/body coordination); b) the physical interface must give positional tactile feedback (in the sense that a flat or merely decorated surface does not, and thus some kind of variation in surface, texture, or resiliency can consistent give the user something tactile to which to spatially orient his or her trained automatic muscular adjustments and correction); and c) these physical qualities of the interface have to be standardized and unchanging, so that they provide very similar tactile information in every instance.

3. CONTINUOUS VS DISCRETE

In the development process of the interface, we found it helpful to track the concepts of 'discrete' and 'continuous' through three areas—musical outputs, tactile feedback, and sensor processing. The goal of reimagining the piano keyboard—into a form in which the pitch, volume and timbre of each note could be continuously controlled without a loss of capability with respect to discrete outputs—emerged from a set of assumptions about desirable outputs for a versatile musical instrument.

3.1 Musical outputs

Even if one considers majors areas of music on a spectrum from rhythm, harmony, to melody, we see that conventional musical outputs require discrete, identifiably separate beats or notes, on one side, and more continuous variations in pitch, volume, and timbre on the other side.

We consider a single output a sound with pitch, volume, and timbral characterstics which has a particular duration. Variations in these parameters can either take place continuously within the duration of such an output, or variations can take place between members of a set of discrete outputs. Typically, discrete variations between outputs are more common in rhythmic musical outputs, especially at faster tempos, whereas continuous variation within an output is more common in melodic outputs, especially at slower tempos. To achieve the broadest range of control, one would want to be able to maximize the capacity for discrete variations between outputs and continuous variations within outputs, in terms of pitch, volume, and timbre, and to do so without loss of accuracy.

3.2 Tactile feedback

This aspiration with respect to musical output has to be related to a tactile feedback system which allows one to input both discrete and continuous variations in a way that enable accuracy and real-time micro-adjustments. Specifically, a given range in pitch, volume, and a particular variable that changes some aspect of timbre can be mapped to the x, y, and z axes of a touch-sensitive surface. However, if the surface is flat, then accurately finding the correct locations for discrete or even just starting pitches, for example, is highly problematic.

In the case of the Seaboard, the three-dimensional input surface, made of silicone (see Figure 2), has a wave-shape form where the peaks of the waves produce, when pressed, musical notes corresponding to the notes of a standard musical keyboard. In this way, the Seaboard can, to a significant extent, mimic a conventional keyboard in its operation with respect to enabling the musician to polyphonically play a set of accurate discrete outputs. For example, by pressing on one of the 'peaks' or 'crests' and vibrating a finger, an oscillating signature can be generated by the sensors, which will be interpreted by the processor as a vibrato. In addition, the shape of the surface means that a player can also play into the troughs, i.e. the areas between the crests, to produce microtonal pitches between any half or whole step. Since the input surface is in places continuous, it is able to produce smooth glissando effects on the keyboard.

As shown by Goebl and Palmer [2], tactile information makes an important contribution to the timing accuracy of piano performances. The interface provides three distinct forms of tactile feedback to the user. Firstly, the texture, angle, and other characteristics of the three-dimensional top surface (see Figure 2) give the user immediate information about the location of the touch, in a way that would be impossible on a flat uniform surface where there is no tactile basis for spatial orientation. Secondly, the soft resilient material transmits forces back to the user to provide further tactile feedback to the user who will be able to sense the amount of pressure that he is applying to the interface. Thirdly, the soft material amplifies the variation in the sur-

Figure 2: Closeup of the silicone surface of the Seaboard.

face area of the tactile feedback.

In these ways, the tactile feedback provided by the Seaboard has been designed to maximize the capacity for discrete variations between inputs and continuous variation within inputs, in a way that intuitively matches with the demands of musical outputs.

3.3 Sensor processing

These observations about discrete and continuous musical outputs, and user inputs, relate also to a distinction between two kinds of sensor-processing paradigms, related to the distinction between discrete and continuous touch interfaces found in Hinckley and Sinclair [4], and the discrete and infinite types of sensors described by Vertegaal et al[8].

A given sensor or array of sensors can provide anything from a single binary message to a continuous flow of high resolution data with respect to multiple parameters.

Currently, most user interfaces for the capture of physical movement or touch fall somewhere on a spectrum between two extremes which could be called 'Discrete Control Interfaces (DCI),' which use a set of discrete sensors, which can register either an on or off position to provide simple discrete inputs, and 'Continuous Action Interfaces (CAI),' which register spatial or gestural movement in time to enable more complex inputs based on continuous movement. Ultimately, the spectrum is defined by levels of resolution and numbers of identifiable, distinct parameters, but in practice, especially with respect to pressure based tactile input sensing, the distinction between continuous and distinct is a relevant one.

The DCI side of the spectrum is typified by simple switches and arrays in devices like typing keyboards, and other interfaces that use direct analog (usually switch-based) controls that usually simulate a mechanical action, while the CAI end of the spectrum might be typified by something like a Kinect tracking system that gathers a rich set of data which can then be mapped in various ways. A piano keyboard does measure a continuous action with respect to striking velocity, but is clearly on the DCI side of the spectrum. In the middle of the spectrum we find technologies such as touch screens, touchpads, other two-dimensional touch sensitive interfaces, and devices like a computer mouse, which use a rolling ball or some other continuous action apparatus that allows for continuous input, but might be more limited in terms of the number of parameters that they can track.

The advantages of DCI interfaces are that they allow for clear discrete inputs and they typically form a tactile and rich kinaesthetic input feedback system that does not rely on visual confirmation, since the user can feel a responding pressure when he depresses a key, for example. These advantages relate not just to the kind of sensing device but also to the design of the input surface, the topmost part of the interface with which the user actually interacts. In the case of typing interfaces, the springing quality of a typing keyboard allows the user to understand at the level of kinaesthetic perception that a key has been depressed, and the contours of the individual keys allows the user to make micro-adjustments to facilitate constant, fast, accurate typing without having to look at the keyboard. Indeed, tactile cues have been shown experimentally to strongly affect the accuracy of experts in carrying out touch-typing tasks [7]. For the musician, visual feedback has a greater role during the learning phase than the expert phase, when tactile information about finger location and action and habitual skill play an increasing role in navigating the fingers about the keyboard [8].

The disadvantage of DCIs is that they are limited in the types of input that can be made, especially when the goal is to input quantitative or continuous information, as opposed to qualitatively separate, distinct commands. On the other hand, CAIs have the advantage of allowing for continuous input and subtle or complex forms of information to be communicated very quickly. For example, touch-screen interfaces allow the user to choose between an arrangement of options that can be simultaneously presented in an easily understandable manner.

In the Seaboard design, we found that by using an array of pressure sensors, and then implementing an algorithm which tracked each input we could offer some of the features of both kinds of interfaces. In other words, the non-flat nature of the Seaboard surface, in conjunction with its hybrid sensor-processing paradigm, means that one can choose whether to play a note in a musically discrete or continuous way. Since the Seaboard enables seamless transitions for both discrete input (e.g. inputs to generate the notes of a chromatic scale) and continuous inputs (e.g. glissando and slide effects, timbral and dynamic variations in real time), it is ideally suited for the complexity of both enabling discrete and continuous real-time, note-by note polyphonic variations in pitch, timbre, and volume.

4. PROTOTYPING

The Seaboard has gone through three prototype iterations; the first was a concept non-functioning prototype, the second a small working prototype, and the third a full-size working prototype. Each prototype has allowed us to resolve particular problems and questions that have arisen during the design and development process.

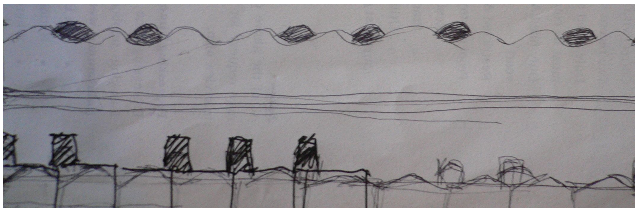

Figure 3: The first sketch of the Seaboard concept.

The first prototype was a concept prototype was based on the sketch shown in Figure 3. The goal was simply to model the main idea in a physical way, and no attempt was made to make it function at that stage. Primarily, then, the Seaboard 1 gave the opportunity to work on the particular shape of the surface, and to test a variety of possible materials. The surface of the Seaboard had to simulate the physical layout of a piano keyboard and the basic size of the distance between each 'wave' was thus given. The trade-off between replicating the exact height differential of the black and white keys on the one hand and making a surface that was gentle enough in its curvature to allow for easy sliding between positions (and thus pitches) was explored. The relative roundness of the keys, as well as the ways that the surface should extend above and below the key also had to be tested and resolved. In terms of the material, it was necessary to find a solution that had the right level of 'give' and yet also had a fast response time and allowed for a diffusion of forces from the top of the surface through to the sensors underneath. Seaboard 2 was the first working prototype, and thus its development also encompassed the selection of sensors, the electronics to make them work and send correct data, and of course a significant amount of software development. Seaboard 3 has allowed us to develop a more mature prototype and software algorithm, discussed in overview below, and otherwise to resolve all the design questions in a more complete way.

4.1 Input

Marshall and Wanderley [6] find that FSR sensors are the preferred input sensor over linear and rotary potentiometers for relative dynamic control, required for vibrato effects. The input from the Seaboard is via an Arduino Mega multiplexed to provide readings from the array of FSR sensors, each with values ranging from 0 to 1023. The sensor values are currently sampled at approximately 55Hz which provides a relatively low latency when playing.

4.2 Output

The Seaboard sends MIDI information to a sequencer that is used to generate sound. For each note sent, we require the ability to change the volume and pitch of each note, and thus we set up separate MIDI channels for the maximum number of simultaneous notes we wish to send (typically 8). We have made use of Logic and Ableton Live as audio sequencers with which to generate sound from the interface. It is also possible to send OpenSound Control (OSC) messages [9] to communicate the amplitude and pitch of each note.

4.3 Algorithm

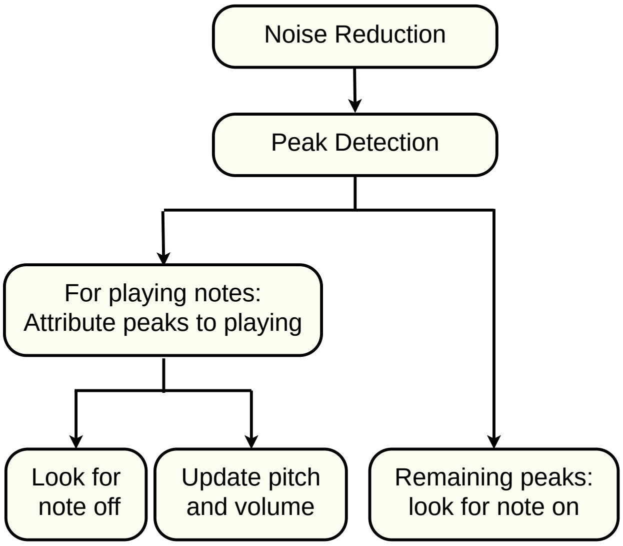

Figure 4: Software Architecture

A diagram showing the design for the software architecture is shown in Figure 4. A noise reduction process makes use of the the maximum sensor values experienced when the instrument is not being played and reduces the sensor values appropriately to prevent false triggering. We then look for peaks in the range of sensors, that is, where a sensor has a pressure value greater than both the adjacent sensors. We calculate a localization in proportion to the pressure that determines each peak's central location and overall pressure. Every MIDI note that is sent out from the Seaboard has an associated location and pressure in terms of the sensor array. Thus, for each playing note, we find the closest peak that has not yet been attributed to an existing note and depending on the pressure, we either update the location and pressure associated with that note or else send a 'Note Off' message and remove the note from our list of playing notes. Then we iterate through any remaining unattributed peaks and if the pressure is greater than a set threshold, we send a 'Note On' message and add the note (with associated peak location and pressure) to the list of playing notes. A mapping function is used to translate between peak location and continuous note location.

5. CONCLUSION

In this paper, we presented the Seaboard, a polyphonic interface that provides continuous dynamic control over the pitch and volume of each note. We have described the iterative design process that led to its construction, highlighting the ethos of the design and the importance of rich kinaesthetic and tactile feedback in new hybrid interfaces that enable both discrete and continuos control.

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