Enhancing the Expressivity of the Sensel Morph via Audio-rate Sensing

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ABSTRACT

This project describes a novel approach to hybrid electro-acoustical instruments by augmenting the Sensel Morph, with real-time audio sensing capabilities. The actual action-sounds are captured with a piezoelectric transducer and processed in Max 8 to extend the sonic range existing in the acoustical domain alone. The control parameters are captured by the Morph and mapped to audio algorithm proprieties like filter cutoff frequency, frequency shift or overdrive. The instrument opens up the possibility for a large selection of different interaction techniques that have a direct impact on the output sound. The instrument is evaluated from a sound designer's perspective, encouraging exploration in the materials used as well as techniques. The contribution are two-fold. First, the use of a piezo transducer to augment the Sensel Morph affords an extra dimension of control on top of the offerings. Second, the use of acoustic sounds from physical interactions as a source for excitation and manipulation of an audio processing system offers a large variety of new sounds to be discovered. The methodology involved an exploratory process of iterative instrument making, interspersed with observations gathered via improvisatory trials, focusing on the new interactions made possible through the fusion of audio-rate inputs with the Morph's default interaction methods.

Author Keywords

Electro-acoustic instruments, Real-time audio processing, Physical Interface, Sound Design

CCS Concepts

•**Applied computing** → **Sound and music computing;**
•**Hardware** → *Sound-based input / output;*

1. INTRODUCTION

The Morph is a new multi-touch interface created by the company Sensel. It is a 240mm by 138mm multi-touch pressure sensitive control surface that is provided with an API directly from the developers[1]. This makes it easily re-configurable and encourages experimentation across different domains, including musical interaction. The interface senses pressures ranging from 5g to 5kg per touch, with a resolution of 15 bits and a multi-touch limit of 16 simultaneous inputs. It is capable of running at 125Hz with a latency of 8ms and tracking precision of 6502dpi in *Full resolution Mode*, or at 500Hz and 2ms latency at a lower precision in *High Speed Mode*[1]. The Morph comes with native support for overlays: modular silicone surfaces with various layouts that attach magnetically to the interface and change how the hardware responds to inputs (Figure 1). At the moment of writing, there are 8 different overlays for the Morph, each providing an unique interactive interface for different purposes. The overlays are detected by the Morph that loads a pre-saved mapping scheme when one is attached. However, it can also be used without an overlay, providing an opportunity for slightly more subtlety and nuance in performance, as direct-touch interactions without an overlay captures user input with no barrier.

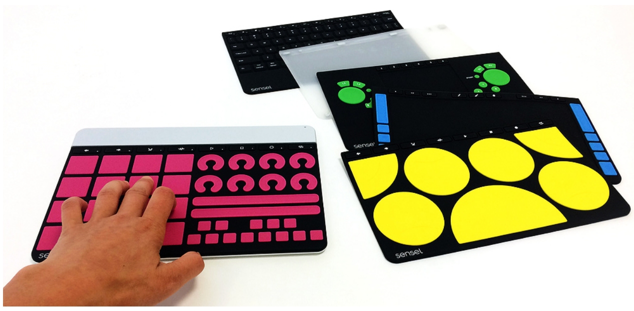

Figure 1: Sensel Morph and overlays

The device makes it easy to interface with a computer in many applications, but due to the relative low sampling frequency (even at 500Hz) it cannot be used to detect audio events that might encode useful information such as sharp impacts that generate higher frequencies, or even distinguish materials of impact from one another (fingertip / knuckle / nail). This projects explores the benefits of augmenting the Sensel Morph with audio-rate capabilities by creating a new musical interface that uses an extra real-time signal captured by a simple contact microphone as the source for an expressive synthesizer built in Max 8[1]. It is worth mentioning that the use case chosen for this application serves as an example of the combined technologies, but the possibilities expand beyond those covered in this work.

2. BACKGROUND

There are many existing instruments and products based on touch and physical interactions with the body of the instrument, combined with digital or analog processing. These include projects such as Aimi's Sampled Acoustics approach

[1] https://cycling74.com/(accessed: 27.1.2019)

NIME'19, June 3-6, 2019, Federal University of Rio Grande do Sul, Porto Alegre, Brazil.

[2], Merrill, et al.'s Sound of Touch[3], Tomas' Tangible Scores [4], Dahlstedt's hybrid digital keyboard [5] or Lahdeoja's augmented electric guitar [6]. There are also commercial products available, aimed at augmented everyday objects such as tables, etc. such as the Mogees add-on for iOS devices (based on a contact microphone and machine learning software).[2]

3. IMPLEMENTATION

This project is built using three core technologies. First is the Sensel Morph, utilized without any overlays in order to avoid potential audio filtering by the silicone pad, as well as preserving the absolute minimum force detection threshold for the maximum range of expression. The second component is a piezoelectric transducer connected to an audio interface. The transducer is in direct contact with the top metallic part of the Sensel. Lastly, there is Cycling 74's *Max 8* (previously known as *Max/MSP*) tying the two hardware elements together as well as providing the audio processing platform.

3.1 Hardware

There are several types of piezoelectric transducers or contact microphones that could be used for capturing the signal form the Morph, but due to availability only three have been investigated: a clip-on, dampened one sold as acoustic guitar pickup, and two bare bone piezo discs with diameters of 1 and 2 centimeters. Since most such devices come without proper documentation, the frequency response of each transducer is unknown, and the discrimination has been made purely on listening tests conducted between the authors. The criteria observed was the captured difference between several types of impact materials (finger, nails, plastic, rubber), strengths and techniques (direct hit, brush, hit+brush, scratch, etc.). Based on this criteria is was concluded that the guitar pickup was the least sensitive to variation, probably due to the damping material on top of the piezo disc. This translated into a low-pass filter-like behavior, capturing most hits with various materials in a similar way. An exception would be the brush and scratch interactions, due to their time domain characteristics that makes them easily identifiable. When it comes with the two piezo discs, the larger one captured a higher amount of high frequency content, making it the most sensitive of the three, for the current application.

Each sensor was tested on various locations on the Morph concluding that the highest fidelity signal is captured on the touching surface, but the most convenient is the exposed metal middle portion on the top of the interface. This was the position where the sensors was placed for this project. The underside of the device also provides good signal representation but proved to be susceptible to friction sounds produces by the Morph's micro-slides on a table. It is worth mentioning that the Morph has rubber feet that are 0.75mm thick providing sufficient dampening to decouple interface from the table.

A constant between the three investigated transducers is the frequency response characteristics of the Morph that made discrimination between some type of hits more difficult. This was particularly evident when performing similar hits with the finger tip, the nail and rubber. The resulting frequency response is fairly similar as can be seen in Figure (2). The piezoelectric transducers were connected to the computer through a Behringer UM2 audio interface and sampled at 44.1KHz, with a buffer length of 256 samples.

[2]https://www.mogees.co.uk/ (accessed: 27.1.2019)

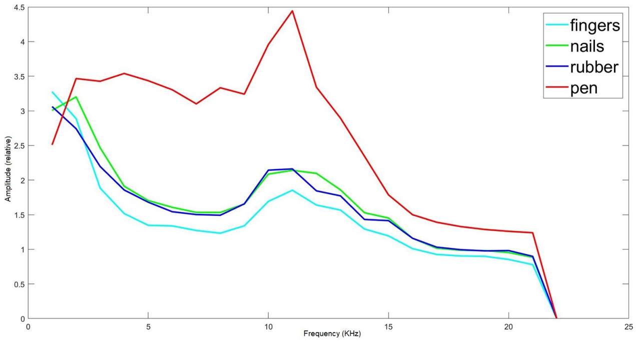

Figure 2: Average frequency response of 100 hits

3.2 Software

The software side of the system was build in the Max 8 environment that supports the Sensel Morph natively, and offers a plethora of audio processing tools.

3.3 Impact discrimination

Before explaining the signal processing chain, it is worth mentioning that an initial attempt at real-time discrimination between interaction materials based on the captured audio signal has been partially unsuccessful. According to Hjortkjaer and McAdams, both temporal and spectral cues can be used to discriminate between materials and action categories in impacted sounds[7]. The authors found though that for single, discrete hits, temporal cues are more reliable, while spectral cues are beneficial when resonance occurs, or there are repeated hits in a short time period. With respect to this, three methods have been implemented with various degree of success. These discriminating factors were used as training data for a supervised machine learning (ML) algorithm implemented in *Wekinator* [8]. For each method, more than 100 samples for each type of hit were recorded as training data.

Spectral centroid analysis was the first attempted method. The ML system could not discriminate at all between hits with the tip of the finger, nails, rubber or a pen, outputting arbitrary classification with no observable consistency. This may have been due to the naturally occurring filtering that the physical construction of the Morph provides (Figure 2).

The second discrimination method used a bounded-Q analysis of an incoming sound to detect onsets of percussion instruments, as implemented in the *bonk~* object developed by M.Puckette [9]. Two independent trials have been made with 11 and 22 filter banks, and the results were consistent between them. The discrimination between pen hits and everything else was reliable, working for almost all amplitudes of hit force. The results were not as clear when it came to differentiate between finger tip, nail and rubber, but there were several cases when the algorithm consistently detected nail hits. This required a particular interaction technique of hitting the morph with the back of the nail at an angle of approx 45 degrees. When it comes to classifying different types of interactions, *Wekinator* was especially successful at differentiating brushes and scratches from hits and knocks. Similar results were obtained from using the built-in classifier implemented in *bonk* , but with less accuracy.

The last discrimination method looked at a pure time domain characteristic in an attempt to improve the existing results. An augmented envelope follower algorithm was implemented, that calculated the maximum difference between two consecutive samples, on the assumption that a hit with a harder material will have a shorter attack than a similar hit with a softer material. While the results were sometimes accurate, the main difference seemed to come from the actual hit force rather than the material, as a hard object will hit with a higher force due to the smaller area of impact.

Because of the inconsistency in the discrimination, the materials' impact characteristics have been deemed unnecessary for this stage of the project. Nevertheless, considering that all the audio produced by the system originates in the signal captured by the piezo disc, an audible difference between materials is still present in the system.

3.4 Signal chain processing

The signal chain is separated in four distinct stages: pre-processing, envelope, manipulation, and effects. All sounds were produced using the exact same patch, with minor variations in the envelope stage.

The pre-processing stage aims at preparing the signal for the next steps by eliminating unwanted spectral components while producing a usable dynamic range. To achieve this a total of 3 filters are used in series: one state variable filter(SVF) in band-pass mode tuned at 50hz to reduce the electric hum, one biquad resonant high-pass filter with a cutoff frequency of 5500Hz and a Q of 0.1, in order to remove the noise introduced by the audio interface and a subtle boost in the frequencies above 5000 was applied in order to compensate for the decrease in sensitivity introduced by the Morph's body, as seen in Figure 2. The next step in this pre-processing stage is to apply a noise gate with a threshold just under the noise floor, followed by compression.

The envelope stage dictates the temporal characteristics of the signal being mapped to the amplitude, and it is only triggered by touching the Morph on it's sensor area. If the aluminum case or the piezo are touched, the following two stages are bypassed, feeding the audio signal directly into the global effects. Several envelopes are used, all of which feature a 4 point Attack-Decay-Sustain-Release structure(Figure 3). Since most sounds that can be produced by interacting with the Morph are impacts, all envelopes used have a relatively short attack time.

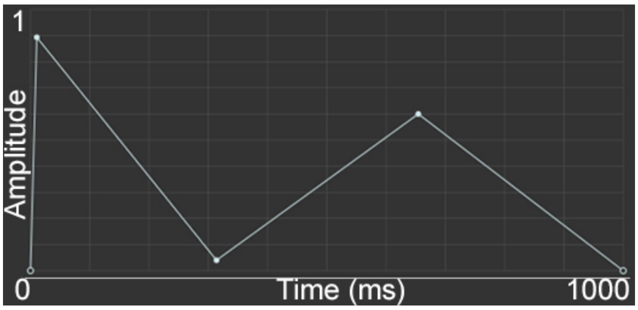

Figure 3: Example of used envelope

The next stage deals with manipulating the incoming signal in order to afford expressivity and produce rich and interesting sounds. The first step in this stage aims at enriching the spectral characteristics of the signal. This is achieved by applying a time domain frequency shift to produce an extra series of harmonics followed by soft clipping, providing overdrive to enrich the result. This process is repeated to further enhance the spectral content. The resultant signal is pitch shifted (transposed) with a variable glide time using a ZTX-based real-time pitch shift [10]. All the parameters described so far are user controllable. From this point on the signal splits into left and right channel, one going into the effects, while the other is further over-driven before passing through a resonant band-pass filter with a variable center frequency that is user controlled.

The final stage consists of a stereo pair of delays with 5 lines with fixed lengths and gains. This is done to create an optional rhythm in the sounds. There is no feedback in the delay implementation. The dry and delayed signals are passed to a pair of reverberators with identical parameters, as described by [11]. The final stereo signal is filtered using a state variable filter in low pass mode, with user controllable cutoff frequency.

3.5 Parameters and Mapping

The mapping is done using a many-to-many approach[12]. The aim of this method is to create an expressive interface that provides a certain complexity level to the user, as suggested by Hunt et. all [13]. The authors claim that by providing a challenge to the user, the reward from interacting with an instrument with complex mappings provides a feeling of better expressivity.

The parameters provided by the Sensel Morph's API are as follows: x-y coordinates, force, as well as the number of detected contact points. The API provides a detailed description of the contact area's shape, but since most expected interactions are short hits, thus having an uncontrollable contact shape, these descriptors have been ignored. All values have been normalized based on the author's experienced extremes.

The X coordinate of a detected impact point was mapped to the center frequency of the resonant band-pass in the manipulation stage. The mapping is exponential from 20 to 1000Hz, left to right. This is the main tonal control of the entire interface; therefore it needs to be explicit. By using a previously known mapping scheme: left for lower tones right for higher ones (as found in a piano) it should not provide any challenges for the user.

The same coordinate axis is mapped to the transpose function as described in the manipulation stage. The overall range is 4 octaves, left to right, with no shift in the middle of the Morph. The mapping is linear and is continuous. This parameter's effect is directly linked to the glide time.

The Y coordinate is mapped to three distinct control parameters. The most noticeable impact comes from the global SVF's cutoff frequency, that is mapped linearly from 20 to 3000hz, bottom to top. This effect is emphasized by a perceived increase in amplitude as hits on the top part are closer to the pickup. Furthermore, the Y axis dictates the amount of frequency shift in the manipulation stage. The mapping is exponential, from 1 to 11, top to bottom and the same value is passed to both frequency shifters. This parameter controls one aspect of the spectral richness, not related to the pitch shifting. It should be noted that the two described controls work in opposite directions, creating a harmonically rich, but filtered sounds on the bottom side of the Morph, and less filtered sounds closer to the top. Lastly, Y is mapped to the glide time of the pitch shifting algorithm. It ranges from 1 to 10000ms and is mapped linearly.

The last parameter, the force, was mapped to the amount of overdrive applied in between frequency shifters, as described in the manipulation stage. Its spectrum is from 1 (no overdrive) to 11. It is worth mentioning that force is updated in real time, having a behavior very similar to after-touch.

4. INTERACTION TECHNIQUES

This section will describe the intended and discovered interactions that produce interesting and desirable sounds using the system. This is not a complete list of sounds possible, but rather an attempt to describe the wide range of interactions possible. Some of the action-sounds described below can be witnessed in the video associated with this paper.

Single percussive hits probably come to mind first when seeing the Morph. Playing it like a finger drum pad with either one or two finger produces impact sounds that range from a sub bass kick drum sound (reminiscent of the Roland 808 kick) to sounds similar to hitting an empty glass bottle, depending on the hitting position and intensity. It is somewhat easy to play in tune if one memorizes the locations for certain desired notes. A variation of this interaction uses the knuckle to knock on the Morph. However, this action will most likely clip the signal as such motions are usually associated with a higher forces.

Multiple finger hits from both hands in rapid succession create an intricate pattern that either descends or ascends in pitch depending on the tapping order. This can be reminiscent of rain-stick sounds, partially because of the noise component present in the incoming signal and partially because of the delay effect that further adds to similar sounds to the mix. This motion usually applies less force on the device, thus creating less of a tonal sound.

As mentioned earlier, impulses coming from hands have a similar spectral characteristic, therefore producing rather similar tonal results. An exception to this rule is the motion resembling the *Nike* swoosh. If passed to an envelope similar to one in Figure 3, it creates a two-stage sound with a sharp,noisy attack and decay, followed by a more gentle, tonal sound that uses the manipulation stage to a higher degree. This motion can accentuate the pitch-shifting characteristic and produces nice bass tones if used on the left side of the Morph.

The Morph's contact surface is covered with a very slippery material, but with enough practice one can produce a stick-slip motion creating complex rhythmical and tonal sounds, depending on the sliding direction. For instance, if moving diagonally from bottom left to top right, the sounds increases in pitch, but at the same time it opens up the global SVF, offering a crescendo effect. This motion is usually achieved by pressing hard on the Morph, an action that is directly mapped to an overdrive parameter in the manipulation stage.

Interacting with the Morph is not limited to finger/hand motions and can be extended to virtually any object, with respect to the Morph's physical dimensions. One object that produced pleasing results was a metal case filled with M2.5 screws slid on the Morph produces an atonal, rhythmically rich sound. This is especially interesting when tossed on the Y axis, thus opening or closing the filter. This sound can be associated with riser sound, popular in electronic music, but considerably richer(risers are usually filtered noise). Another interesting sound was produced by rolling a AA battery over the entire width of the Morph. This interaction produced a tonal (de)crescendo, similar to a tone sweep. If the rolling is rather diagonal than horizontal, the filtering and frequency-shifters adds character to the sound. A last example of unique action-sound can be found in a spinning top toy, a coin, or a common glass rotating in balance on the surface. There is a continuous contact point creating a long, evolving sound. The more the object moves on the surface of the Morph while spinning, the greater the variation in the sound it can create.

5. DISCUSSION

The main contribution of this project is the augmentation of the Sensel Morph with real-time audio input to bring back the possibilities of acoustic interaction. The Morph is an outstanding device in itself, but it can be transformed into an electro-acoustic instrument with audio augmentation. Many such instruments have been built recently, as mentioned in the background section, but this project is a hybrid in a rather different way - the controls represent the sound sources and the two cannot be decoupled without a redesign of the mapping layer. Bringing the richness and diversity of acoustically produced sounds as part of the a digital instrument, greatly enhances the sonic range, the action-sound palette and its expressivity. One can physically interact with the device in infinitely many different ways serving as an open ended platform for exploration and sound variation in the hands of a performer. This key element as well as the introducing the stochastic nature of physical action-sound, so hard to reproduce synthetically, makes the augmented Sensel Morph an unique instrument. As mentioned before, the software implementation presented in this project serves as an example for the possible physical interaction and it's correlated sounds thus it can be concluded that the augmented Morph could have totally different sonic characteristics.

5.1 Expressivity and playability

All acoustic instruments come with a physical challenge over control and usually have a balance between the amount of control over each voice and the number of voices[12, 13]. The same can be said about this project. On top of that, having the control gestures have a direct impact on the sound captured by the piezo, further increasing the cognitive load. This does not mean that the instrument is impossible to play, but it does require some practice in order to have control over the outcome. Nevertheless, the opportunity of acoustical control available literally at the player's finger tips is a strong feature, and makes for the largest portion of expression possibilities [14].

5.2 Repeatability

Acoustic sounds have complex spectral and temporal characteristics, such that absolute repetitiveness is difficult, if not impossible via human control. The same can be said about the gestural interaction controlling the sound, especially true since the Morph does not have any visual or haptic cues to help the player in their quest for consistency. However, the system will react consistent to identical inputs, a characteristic that is common among most acoustic instruments. This does not mean that all features are equally easy to control. For instance, finding the exact location on the X axis where the resonating filters are in a certain tuning is difficult, because there are no real reference points on the Morph. Quantization could be a possible solution for this problem, but the result would be more sterile, perfectly repeatable sound known to push players away in longer-term playing.

5.3 The sound

The sound of the system is dictated by the processing done in Max 8. The focus during development was on action-sound aspects, and how could those be translated into musically sufficient and rich sounds. In order to achieve this, the mapping scheme *many-to-many* provided rich sound variations with little effort, but understanding the complexities and how to control them is not trivial. The system is flexible enough to provide a wide sonic palette that ranges from percussive sounds to tonal, melodic ones. Considering that the interaction object and it's material have a large impact on the resulting sound (a characteristic of percussion instruments) and the interaction technique plays a similarly important role, it is hard to describe *the sound* of this system. Nonetheless, there are physical constrains regarding the hardware and it's proprieties. For instance, the Morph, like any other object, has a resonant frequency that is accentuated through the processing developed. In addition, the frequency response of the piezoelectric transducer could be improved through the use of an impedance-matching transformer, and/or the use of a less resonant ceramic disc type of piezoelectric transducer. These factors contributed to sometimes distorted and overly-accentuated frequencies, usually triggered in the middle of the Morph, and might be alleviated by incorporating such hardware improvements.

6. CONCLUSION

This paper presents a multi-touch hybrid acoustic-digital instrument based on augmenting the Sensel Morph, with real-time audio sensing capabilities. The system offers extensive interaction possibilities while maintaining the intuitive aspect of percussive instrumental techniques. The acoustic input from the piezoelectric transducer is used as the only source of audio input. This is processed in Max 8 to enrich the sound and offer a much broader range of possible spectral and temporal characteristics, while offering a high degree of control over the resulting sonic output via the pressure sensing matrix inside the Morph. The instrument affords a large variety of interaction techniques ranging from single finger hits, to more complex and creative actions, like using a spinning top.

The synthesis engine is relatively simple, yet the mapping layer is somewhat complex. This system is only used as an example of the possibilities offered by augmenting the Morph with audio-rate sensing. Nevertheless, the instrument provides a remarkably satisfying experience for a curious player, heavily encouraging experimentation. In the hands of an professional musician it can provide a platform for new sounds, given that the performer is willing to discover and practice new ways of interacting with the musical instrument.

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