SCULPTON: A MALLEABLE TANGIBLE INTERFACE FOR SOUND SCULPTING

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ABSTRACT

This paper seeks to outline the development of SculpTon, a malleable tangible interface for sound sculpting oriented to live performance. Within our concept, shaping sound is an equivalent of physically shaping an object. The recent reflexion on "computational materials" and "Radical Atoms" in TUIs has prompted us to imagine what possible applications in the context of NIME. In our interface the musical expression is made through the use of real-time formant synthesis in the form of a three dimensional, organically shaped object, which can be handled and modified by the user. Firstly, we describe the development and the design principles of the SculpTon interface. Since the notion of malleable interface was already explored in research fields such as TUIs, OUIs and NIME, we are going to recapitulate some previous works. Next, we introduce the technical implementation of the device and the embedded sensor array developed ad hoc. Drawing from such elements, we eventually describe the methods by which useful features were extracted and the mapping techniques used to deploy these features as control data for real-time sound synthesis.

1. INTRODUCTION

Malleability is considered one of the most attractive properties of the digital world [1]. Digital objects are easy to create, modify, replicate, and redistribute. On the other hand, technological artifacts are very often rigid and static. This is a common characteristic that invests most of the musical interfaces available on the market. Very often the action used for deforming and shaping a malleable material, that is sculpting, is used to describe sound synthesis algorithms and softwares for physical modeling [2] . From our point of view this creates a sort of paradoxical situation where "malleable digital sound models" are controlled by "non malleable" interfaces.

Malleable objects have a compliant material quality that invites users to multiple levels of tactile exploration and manipulation. We can easily notice that in relation with malleable artifacts the human hands can transfer and reinforce expressiveness through more degrees of freedom than with rigid objects. The characteristics of these materials impose on the user their own particular affordance, which can also vary during the action. Materials and artifacts with changeable affordance are also more suitable for a whole-hand interaction, which involves also the use of both hands at the same time. Nowadays, a combination of the growing interest in materiality of computation [3] and the advances in creation of computational materials [4] is transforming our thinking about the relations between the physical and digital that goes even beyond the idea of tangible interaction [5]. Through the vision of "Radical Atoms" Ishii et al. [6] are exploring the possibility of merging the physical and the digital using *malleability* as a new trait d'union. They envisioned the idea of *digital clay*, as an ideal physically represented, malleable material that is synced with a coupled digital model. Direct manipulation by user's hands, such as deformation and transformation, of sensor-rich objects and materials should be translated into an underlying digital model immediately to update its internal digital states. By encompassing the vision of TUIs, Organic User Interfaces (OUIs) uses malleability as the main metaphor for imagine new interactions with non planar displays and shape changing interfaces [7].

SculpTon is a malleable tangible musical interface, which uses the metaphor of sculpting for creating and promoting an active and engaging a relation between the performer and the musical artifacts. Our interface seeks to look at the problematic relation between the physical and the digital in musical interfaces, such as the well-known decoupling between the controller and the sound synthesis [8], through the idea of computational materials. SculpTon tries to contribute in the process of building a repertoire of concepts and methodologies to help us to imagine how basic materials could be re-designed through the addition of computational power. We believe that manipulating and getting engaged with material qualities inherent in the physicality of artifacts represent an interesting area of experimentation for artists, composers and designers of NIME instruments, which can led to new aesthetics and more expressive solutions.

2. RELATED WORK

We borrowed the idea of *sound sculpting* from the title of a "virtual musical instrument' developed by Mulder and Fels [9]. In this project the hand posture information and finger movements were employed to manipulate the shape and adjust location of a virtual 3D object. Various physical properties of the virtual object were used to govern continuous sound effects and synthesis parameters. SculpTon tries to explore the actions that transfer the bodily forces onto deformable matter as a peculiar and complex group of expressive musical gestures. This is what we consider as the meaning of *sound sculpting* in this context. As a tangible musical interface, SculpTon uses an embodied approach to musical control, compared to conventional digital musical interfaces. In the area of TUIs we can find projects that are taking the idea of sculpting as a metaphor of interaction, and malleable materials (such as clay) as a reference to employ or mimic [10, 11]. According to Jordà [12] musical interfaces are one of the most successful areas of application of TUIs due to their possibilities of allowing continuos and real-time interaction with multidimensional data, support for complex and skilled explorative interactions. In the area of NIME we can find some relevant projects that explore the idea of malleability and tangible interactions, through the use of different solutions and design strategies. Some of the early examples are the Squeezables [13], The Matrix [14], Sonic Banana [15] and The Sponge [16]. Recently, some projects begin to shift the attentions on the advantage of combining material properties with embedded sensor technologies. If Kiefer [17] uses foam as an input material, conductive thread and fabric were tested by Chang and Ishii [18], as well as silicone [19]. Also the acoustic properties of malleable materials started to be explored like in the Music Ball Project [20]. As a new interface, SculpTon is situated between these two branches of research, applying the most recent reflections in TUIs about computational materials to the development of multiparametric digital musical interfaces that are exploiting the peculiar characteristics of malleable materials augmented with sensors and embedded technology.

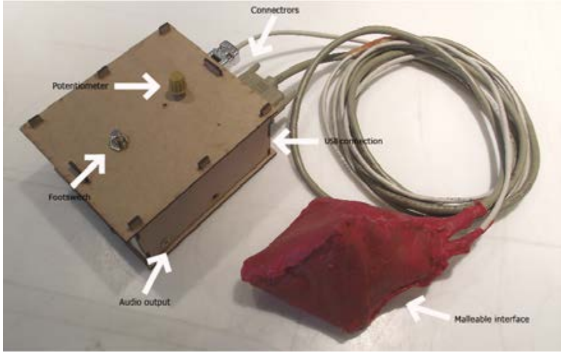

Figure 1: SculpTon. The malleable interface and the stompbox.

3. SCULPTON

The aim of SculpTon is not to propose an ultimate framework for approaching the problem of expression in musical interfaces, but to introduce a methodology for exploring such questions under the lens of materiality in tangible musical interfaces. From a design point of view our goal was to build a tangible interface with malleable organic characteristics, capable to keep track of subtle and detailed physical manipulations, which combine many input attributes with multidimensional control. The SculpTon interface does not mimic any existing traditional acoustic or electronic instrument, but it has a peculiar and distinctive feel, characterized by its organic appearance and handling. SculpTon is inspired by and incorporates some ideas from the agenda of TUIs and OUIs, with a special emphasis on computational materials and embodied interactions. The system's principles are self revealing and user could quickly and easily make sense of the interface using only their experiences of the physical world, such as manipulative tasks. In our work the understanding of the properties and sensations caused by the surface of a material object received through the sense of touch -the textural quality of the interface- became crucial. SculpTon consists of a physical interface, a stompbox and a software (Figure 1). The physical controller is composed of an array of sensors (analog, digital and acoustic), 4 LED for visual feedback embedded in a malleable structure covered with an opaque latex hull. The stompbox represents an useful bridge between the physical interface and the software. The final version is a 30x30x20 cm laser cutter MDF box that contains an Arduino Mega board[1] and a low-power audio amplifier. It's equipped with some connectors (two serial plugs for the malleable interface and a USB for the serial communication with the laptop) on two sides, a footswitch and a potentiometer on the top. On the software side, a framework for Pure Data was developed in order to manage different routines, data processing, mapping and sound synthesis.

Figure 2: Two 3D printed structural elements: the vessel and the nodes.

4. IMPLEMENTATION

The SculpTon tangible interface was completely designed and produced by the author. The development was documented through some internal academic reports and a dedicated website[2]. As a part of our methodology, we decide to employ open source tools (both hardware and software) and digital fabrication techniques (such as 3D printing and laser cutting) not only as a way of rapid prototyping, but as a source of new compound materials and customizable elements. Additionally, SculpTon seeks to demonstrate how the use of these tools can be used in the design of affordable, functional, repeatable, and sharable highly personalized musical interfaces. We start to describe the tangible interface from its surface that is a latex skin, which presents an irregular, organic and rough appearance. Latex was chosen first of all for its tactile and elastic properties, but also for its flexibility in design. One of the disadvantages of latex is its insufficient durability but, on the other hand, it is also easy to repair and even reconstruct. The

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[1] `http://arduino.cc/en/Main/arduinoBoardMega`

[2] `http://sculpton.tumblr.com`

structural elements that are composing the artifact are fabricated with Elasto plastic [3] , a robust and rubber-like elastomer developed for 3D printers (see Figure 2). Within our concept the carachteristics (and limitions) inherent in all of these materials became important and fundamental parts of the sonic interaction. Material properties such as texture, plasticity and elasticity are used as way of interaction and information about the functions and the behavior of the physical interface.

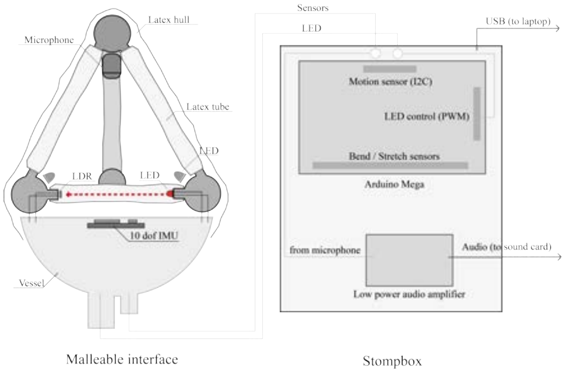

Figure 3: An outline of the system. On the left, a section of the malleable controller; on the right a schematization of the stompbox.

4.1 Sensing through structure

For SculpTon we employed a methodology that attempt not to separate the object that the user deforms and the sensors used to measure it. Instead of adding sensing to already existing objects we started by designing an object with its own sensing capabilities:

- external manipulation –internal behavior,
- physical excitation –relaxation;
- spatial actuation –temporal response.

The result is physical representation of the sonic interactions in the form of three-dimensional object. Through a method defined as *sensing through structure* [21, 22]. we implement a way of monitoring continuous and subtle changes in a physical artifact (Figure 3). The choice of an embedded system derive from its scope of operation, size and cost. An interface characterized with a strong and specific relation between materials, gestures and sound requires the development of a specific sensor technology. One of the major issue was the detection of gestures such as bending, stretching and squeezing. After a survey on the sensors available on the market, we noticed that bend sensors and stretch sensors are normally decoupled. Apart from cost, one of the main limitations are the size and the length of these elements. Drawing from such conclusions we opted for a custom made sensor array, using light as a way to measure deformation. Optical sensing was successfully applied for sensing bending and stretching [23]. We can also find some relevant examples of the use of optical sensing in TUIs for measuring structural strain in physical models [21], and in musical interfaces [8, 19].

4.2 Sensor modules: joints and nodes

The heart of the sensory part of SculpTon is a *sensing structure* composed of six custom made "augmented organic modules" in the form of a tetrahedron (see Figure 3). The sensors are fabricated to measure deformation of the interface, including bending, twisting and stretching gestures. Each of these modules are composed of an optical sensing mechanism embedded in two opposed nodes connected with a stretchable joint. These joints are made of latex tubing, and the nodes are made of a 3D printed Elasto plastic shells. The sensing mechanism is composed of a pair of LED and light dependent resistor (LDR). The material properties are used to keep the structure highly and freely manipulable, but stable and robust. The tubing is keeping the LED and the LDR in complete darkness and severs as a omnidirectional bend and stretch sensing mechanism. In the first version we include inside each tube a metal spring for proving a passive haptic feedback. After some tests we decide to rely only on the properties of the latex (Figure 4). This system is measuring the intensity of the light coming from an LED on one end of the joint with a matching light dependent resistor (LDR) placed on the other end. When the joint is straight the intensity of the light is at its maximum. As the joint bends the tubing occludes the light to a point where the LDR cannot detect any light emitted from the LED. Otherwise, when the the joint stretches, the light perceived by the LDR slowly decrease according to how much the tube is elongated. We noticed also a relation between the decreasing of the light and the time when this phenomena occurs. When the joint bends the light decrease very rapidly, from the maximum to the minimum intensity. On the contrary, when the joint is stretched the light perceived by the LDR never reaches the minimum, but is very slowly dimmed (Figure 5). This behavior is a result from a combination of the optical sensing mechanism and the elastic property of the latex tube: the material applies a resistance when it's stretched, and thanks to the global configuration, makes different gestures recognizable. Before we defined this solution as "organic augmented sensing modules'; with this we mean a combination of a sensing technique (in this case optical) and the

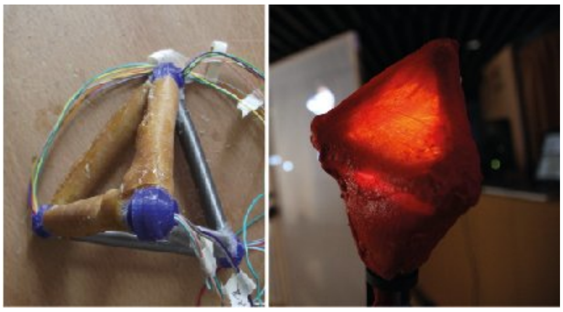

Figure 4: Left: prototyping the sensing structure. Right: the final appearence of the interface.

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[3] `http://www.shapeways.com/materials/elasto-plastic`

properties of the material, with which the organic sensor is made of. The choice of a particular material can not only affect the haptic feedback of the entire interface, but can influence the interaction with the artifact and allowing the sensing of particular gestures.

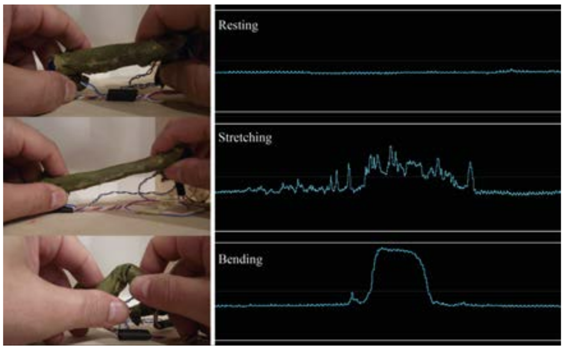

Figure 5: Three main gestures detected by one single sensing module: A) Resting position; B) Bending; C) Stretching.

4.3 Motion and acoustic sensors

After the implementation of the malleable surface we encountered the need of sensing energy and movement in space. For this we opted for complete motion sensor, precisely a 10 dof mems IMU board[4], composed of a three axis accelerometer, gyroscope, pressure sensor and a compass on a single tiny, low power board, communicating with the mirco controller through the I2C protocol. With the help of some further calculations[5] we are able to extract features such as acceleration, rotation, orientation, the yaw, pitch and roll of the entire artifact. The performer can also calibrate the motion sensor directly on the stage using a footswitch, placed on the top of the stompbox. This motion sensor is hosted (at the bottom of the seining structure) on a 3D printed vessel, also made with the Elasto plastic. The function of this element is to support the sensing structure and stabilize horizontally the motion sensor. As we can see in Figure 3, inside this structure there is an electret microphone and an integrated motion sensor. The microphone is placed inside the sensing structure and it's capturing the sound of the friction produced between the hands and the latex cover of the device. For preventing interferences and malfunctions the microphone was incapsulated into a silicone holder and placed into an additional latex tube. This also represents an interesting sound source and a sensor for detecting additional gestures.

4.4 Final implementation

Sensors outputs are then wired to an Arduino Mega for data processing, formatting and USB serial communication of the sensor data with a Mac OSX laptop computer. The microcontroller was then encapsulated into the stompbox. The tangible controller is connected to it through two cables, one for the sensors, with a 25 pins serial connector, and a 9 pins one for the LED used for the visual feedback. For the sensor data acquisition on the Arduino board we developed a custom made shield, which provides simple and clear connections of the analog/digital sensors, the LED for the visual feedback and the footswitch. This configuration helps the debugging of the interface and an easy setup on the stage. Together with these sensors, the 25 pins connector is containing also the connections of the electret microphone. This element is treated separately and connected to a low-power audio amplifier, which is also hosted inside the stompbox. The gain of the amplifier can be controlled with a potentiometer, then the audio output is provided through a 1/4 mono chassis jack socket. Four LED are embedded into the sensing structure. They are lighting the artifact from the inside. These elements are also providing a minimal visual feedback, by visualizing the acceleration measured by the motion sensor through a light pulsation. This configuration represents first of all, a compromise between the difficulty of embedding all of the electronics in a malleable object and secondly, the necessity of removing the computer from the stage.

5. PERFORMANCE TEST: MAPPING AND SOUND DESIGN STRATEGY

At this stage the major goal was the creation of a design paradigms for mapping deformation and energy to sound. The main principles and some technical implementations are illustrated below.

5.1 Gestures and sound

SculpTon combines several input attributes and, allows different types of interactions, such as :

- to hold, grasp and manipulate the object with both hands and fingers from each side;
- to apply forces, such as pressure and allow squeezing, stretching and other types of deformations;
- the users are required to employ their perceptual-motor skills.

The use of perceptual motor skills is at the core of playing acoustic music where an embodied relationship with an instrument is fundamental to create music with it. Wanderley and Depalle [24] propose multiparametric control as an efficient method that provides a more musical way of interacting with computers. This was demonstrated by Hunt, Wanderley and Paradis [25] through some user studies, and also that complex mapping strategies are more engaging and even can enhance expressiveness better. SculpTon is embodying a digital model of the human voice, implemented through a formant synthesizer. Being the focus of this paper on the research methodology and interface design, the implementation of the synthesis model is not illustrated in detail, but it's fully referenced [26, 27]. However, in Figure 6 we summarize the basic layout of our format synthesizer. Within our concept the coupling between

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[4] `http://www.dfrobot.com/index.php?route=product/product&product_id=818`

[5] `http://www.varesano.net/projects/hardware/FreeIMU`

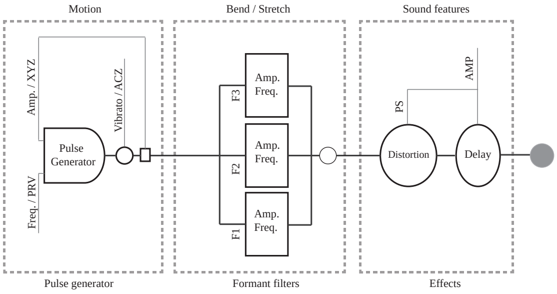

Figure 6: An abstraction of the synthesis model and the mapping.

the physical structure of the interface and the digital structure of the synthesis algorithms represents a key point for achieve a full embodiment of the interaction. The choice of using a formant synthesizer is first of all an artistic choice, justified through two relations :

1. between the physical deformation of the human mouth and the physical deformation of an object;
2. between the energy implied for producing speech and the energy and motor skills used for playing the interface.

Some relevant examples of interfaces for gestural control of digital speech can be found in Fels [28], Cook [29]. From an artistic point of view we are not interested in using SculpTon as an interface for controlling and creating realistic simulations of human voice and speech, but to use it as an interesting, ambiguous and even funny sound space to explore and invests with new expressive meanings.

5.2 Mapping energy, motion and deformation

Through this project we tried to explore an approach for relating manipulative gestures, such as deformation, to a digital model of the human voice, which is physically characterized by some sorts of deformations and use of energy for producing sound. We decide to combine different features extracted from the sensor array through the following mapping strategy, illustrated also in Figure 6. From the integrated motion sensor we calculate a vector from the pitch and roll values (PRV). This vector was directly mapped to the frequency of the pulse generator. Its amplitude is modulated by the magnitude of the acceleration on the three axis (XYZ). Therefore, when the interface is in a resting position -with no energy applied- no sound is produced, but when some strong movements are detected the frequency is increasing or decreasing, according to the of the direction of the rotation and modulated by the amount. Other features from the motion sensor, such as the vertical acceleration (ACZ) are extracted and, after a proper scaling, mapped to the vibrato. Then, the sound is passed through a series of three resonant bandpass filters in parallel. If the source signal is produced by the motion of the artifact, the vowels are literally ’sculpted’ through a direct manipulation of the interface. According to what we said in 4.2, bending and stretching gestures are thus detected through a threshold applied on every single data coming from each joint of the sensing structure. Then, we calculate a vector of the two gesture, and these vectors are combined in other two vectors, two by two. From six sensors now we obtain three control values (F1, F2, F3) for the formant filters. Since in the ScupTon we introduce also a microphone, we implement also some features extraction for this source. At this stage of the development we have not yet introduced the use of the acoustic sound as such, but we are considering to using it as an additional sound layer. When the hands of the performer are moving moving on the surface no relevant sound is captured, but if the user starts to manipulate the object, we can recognize significant variation in amplitude. The sound captured from the microphone is very weak, and additional amplification is required. Extraction of useful data can therefore be achieved with an amplitude analysis and tracking. Having said this, the most meaningful values extracted are the amplitude (AMP), and the peak which is characterizing the staring point of manipulative gestures (PS). These features are then mapped to the control parameters of two sound effects, such as a distortion and a delay. Although, this configuration has given some positive results during performance and tests, the main limitations are its complexity and the rigidity. We believe that a better exploration of different methodologies, such as the use of machine learning algorithms can improve the expressivity of the system and a better exploration of the relations between motor skills, manipulative gestures and the sound synthesis.

5.3 Testing SculpTon

The SculpTon was tested live for the first time at the Ars Electronica Festival 2013, and during 104 in other venues such as MNAC (Bucharest, RO) and IAMASONIC (Ogaki, JP). The aim of these performances was exploring the possibilities of SculpTon through a framework for free improvisation. Sometimes, after the performances, the device was also offered to the public for an hands-on experience and evaluation (see Figure 7). If at a first look the interface appears fragile, these public shows have proved the reliability and efficiency of the whole system. Audience feedback was positive, and what most appealed some listeners was the particular coupling of sound and gestures, the unconventional appearance of the interface, and the physical engagement that the performer can achieve with an interface with such malleable characteristics. Some of them also noticed that, as a solo instrument, SculpTon is quite one dimensional, both sonically and visually. This suggested us some future improvements in the sound synthesis, as well as in the visual feedback. Using the interface with other instruments is also an option that we are taking into consideration.

6. CONCLUSIONS

A system has been presented for the exploration of the idea of malleable computational materials in the context of tangible musical interfaces. Malleability was identified as a key property for creating an promoting an expressive and meaninful relation between a physical structure and a digi-

Figure 7: Left: Performing with Sculpton. Right: a member of the audience tries the interface.

tal model. We believe that a better understanding of the use of computetionally augmented materials can helps the design of NIME instruments and expanding its vocabulary of relations between sound and gestures. With this project we tried also to demonstrate that the use of digital fabrication techniques and open design processes can implied meaningfully not only in the prototyping stage but also in the final realization of a rubust, articulated and unconventional tangible musical interfaces. The next step is a formal user study which will help to improve the design of the whole system.

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