Spyractable: A Tangible User Interface Modular Synthesizer

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Abstract. The purpose of this paper is the exploration of the possibilities that Tangible User Interface (TUI) may offer in the area of sound synthesis, by reconfiguring the functionality of the existing TUI tabletop musical instrument called “Reactable” and redesigning most features, adjusting it to a synthesizers needs. For this research we analyzed sound properties, physics and formation, as well as how human used these features to synthesize sound. Afterwards we present the properties and advantages of TUI technology, and its use in sound and music, distinguishing Reactable, for being the most even musical instrument using TUI. As an outcome we develop and present an initial prototype modular synthesizer, called Spyractable. Finally, we subject Spyractable to users’ evaluation tests and we present the outcomes, making suggestions for further investigation and design guidelines.

Keywords: Sound wave, harmonics, modular synthesis, modules, tangible user interface (TUI), tangibles, patches, graphical controllers.

1 Introduction

Reactable is a tabletop TUI musical instrument, uses specially developed fiducial markers and gestures to produce intimate music [1]. Design was involving the development of a multiuser organ, with simple and intuitive use, without any guidance or manual needed. It produces music from the first interaction and supplies with optical feedback the users, so to make known of its state and use [2]. Users manipulate finger gestures and special fiducial markers (the tangible tokens), that are connected dynamically in a modular analogue synthesis way, on the reactable’s surface, to change sound structure, control its parameters and create music [3].

Even though Reactable has sound synthesis capabilities, it concentrates more on music production and less in sophisticated sound synthesis, introducing just the basic modular synthesis principles [2].

In this paper, sound and sound synthesis, TUI's technology and Reactable's main features and software have been explored and an appropriate interface has been designed to adjust Reactable’s features to a sound composers’ needs. Finally, a small, but adequate, version of a tangible user interface tabletop modular synthesizer has been designed and implemented, so to evaluate if such a venture can contribute to a

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simpler and faster way of synthesizing sounds, with a clearer view of the user's actions that enhances experimentation and creativity. The synthesizer is called **Spyractable** and is able to implement classic and more complex, methods of synthesizing, addressed to users with a long range of knowledge on sound synthesis, starting from knowing the basics to more sophisticated skills.

1.1 Sound

When a sound source is being vibrated, it causes a propagation of periodic changes of the atmospheric pressure. This propagated disturbance is called wave and as travels through air (or any other compressible media), it carries energy. The wave's crests correspond to the compressions, troughs to the rarefactions of the atmospheric pressure and zero prices to atmospheric equilibrium. When a wave reaches an ear, and fulfills some conditions as described later, it stimulates the acoustic nerves and the brain interprets these waves as sounds. The simplest wave that can be discrete, is described the sinusoidal wave. Most sounds in nature are not simple but complex, formed by many different sinusoidal waves. The human ear analyzes sound in its consisted sinusoidal waves and sends different signals to the brain [4, 5].

Wave has the following objective and corresponding subjective characteristics that correspond to its nature and to human interpretation.

Frequency and Pitch: "Frequency" is the characteristic that describes how often the periodical disturbance is being repeated and is measured in Hertz. Frequency is perceived as "pitch". Human ear corresponds to sounds from 20 Hz to 20 kHz [7].

Volume and Loudness: The wave's crests and troughs give the amplitude of the wave that represents the amount of energy carried within the wave (the volume) and is being measured in watts/m2. Human interprets volume as "loudness". Different frequencies with same volume are not perceived at same loudness [4], [5].

Phase: The moment of the time circles of a period when the wave started is called "Phase" and being measured in degrees [5], [6].

Time Envelope: Every sound has a start and an end. The curve describing how the amplitude is being developed in that period of time is called Time Envelope. Time envelope is usually divided into four segments: Attack, is the time from the triggering of sound, till it reaches the sound's crest amplitude. Decay is the time sound is taking from crest amplitude to normal level of sound, as long as it endures. Sustain indicates the amplitude the sound has during its duration and is a percentage of maximum amplitude achieved at Attack time and last segment is Release time. The time the sound endures till it stops, after the sound source stops to vibrate [4], [6].

Harmonic contain – Timbre: Most sounds are sums of many different sinusoidal waves, with each one to have its own frequency, amplitude, phase and envelope. This sum is called harmonic contain and it is this characteristic that make people distinguishing the many different sounds, characterizing as "Timbre". In every harmonic contain there is one louder wave (fundamental) that determines the pitch of the sound. In order a sound to sound fine, all the other waves have to be integer multiples and submultiples of fundamental's frequency, obeying the formula $f_n = f_f * n^{\pm 1}$ The multiple frequencies called overtones and the submultiples sub - harmonics. Every other frequency causes the sound to sound bad / inharmonic [4], [6].

1.2 Synthesizers.

A sound synthesizer is a device that has the ability to produce a wide range of sounds, either imitating existing organs, or producing new sounds that don't exist in nature. Synthesizers use various methods and circuits to handle electrical and digital signal, as waveform analogue, and turn it into sound. It has three parts: **Controller** that sets the pitch and other factors of sound. **Speakers** that turn electrical signal into sound and the **generator** that carries all the appropriate equipment to produce sound. There are three main kinds of synthesizers: Analogue that use electrical signal, digital that uses digital signal and VST's that are computer software [6], [7].

Synthesizers, in order to handle sound, use discrete components to do separated elaborations and formations to the signal, till it becomes sound. The basic units are:

- **Oscillator:** Circuit that produces alternating signal in a circular periodical change, just as a wave. It's the mother of sound [4], [6].
- **Low Frequency Oscillator:** This unit is also an oscillator that produces a non hearable signal between 0.1 Hz and 20 Hz. Its purpose is to slightly modulate other module's factors. If it modulates oscillator then we have "vibrato", if it modulates the amplifier's gain, we get the "tremolo" effect [4], [6].
- **Amplifier:** It multiplies signals amplitude, in order the sound to be hearable. It is also used to "shape" a sound by using a time envelope to its signal exit [4], [6].
- **Envelope Generator:** Unit that produces electric control voltage or digital command. As it name reveals, it is the unit that generates time envelopes [4], [6].
- **Filter:** This is a unit that clips or weakens frequencies within a range, defined by its kind and attributes [4], [6].
- **Effect Processors:** Special circuits that modify the acoustic signal in a way that has to do with its environmental behavior [4], [6].
- **Mixer:** Circuit that adds signals, at specified volume levels, into one unique signal.
- **Modulator:** Modulation is a procedure where a signal modifies some characteristics, as frequency, phase, amplitude and harmonic contain, of another signal. This method is used to shape signals and create sounds or within effects [4], [6].
- **Sequencer:** It's a district, additional unit that produces notes [4], [6].

There are nine basic methods of sound synthesis, but VSTs make it possible to produce some more hybrids. The most important Synthesis techniques:

- **Modular Synthesis:** The base of all analogue methods, the first method used to form different sounds. The composer connects modules using simple cables in order to make the desirable sound, forming many different synthesis types [6], [8].
- **Additive:** It does the opposite procedure of ear, meaning it uses many oscillators, producing frequencies with its own phase, amplifier and time envelope [6], [7].
- **Subtractive:** With two or more oscillators and a mixer we produce a complex waveform that is being filtered with one or more filters, so to obtain the harmonic contain the composer wants [6], [7], [9].

- **Physical Modeling:** It is a method, which uses mathematical models to simulate the cause of the sound, as it happens in nature. A computer calculates the sound wave that will be produced from the knocking of a string with a hammer in a wooden box for example, and oscillates the oscillator in that manner [6], [9].
- **Sample Based:** This kind of synthesis uses recorded samples of organs in all the frequencies. The controller triggers the oscillator to play the corresponding frequency. Usually two or more oscillators are used, then mixed and follow the common procedure, filter, amplifier and effects with LFOs and envelopes. [6], [9].
- **Frequency Modulation:** As described before, frequency modulation uses a hearable signal – modulator- to modulate the frequency of another signal-carrier. Carrier sets the fundamental frequency and modulator the overtones. Overtones volume depends on modulators and carriers amplitude ratio [6], [7], [9].
- **Phase Modulation:** Modulator is a special oscillator that is able to change phase circle velocity. If, for example, phase gets from 0 to 360 in half time, this means that the period of the wave lasts have the time so the frequency is doubled [6], [10].
- **Linear Arithmetic:** Digital kind of synthesis that combines subtractive and sample based methods. It uses two mixed tones. Each tone is made by two sound partials. Partial P is a sample based sound made by a sample oscillator and a time variant amplifier. Partial S is a subtractive sound made by an oscillator, time variable filter and amplifier. The partial P sets the Attack of the sound and partial S the decay, sustain and release of the sound [6], [7].
- **Wavetable:** Digital method that uses a matrix of samples. Some samples will constitute attack and decay and another sustain and release. [6], [7], [11].
- **Granular:** Another computer based synthesis. It is similar to linear arithmetic with many parts of samples lasting less than 50msec (grains). These parts form sound shadows that can be treated like simple waves later on [6], [12].

1.3 Tangible User Interface (TUI)

Tangible User Interface, are graspable, physical or embodied user interface with least differences, and are a physical handle to a virtual function that is being used for one and only dedicated manipulation [13]. In TUIs, physical objects (tokens) are both controllers of digital information and physical representation of it [14].

TUIs have the following attributes regarding representation and control [14]:

- Physical representations, computationally coupled to underlying digital info.
- Physical representations embody mechanisms for interactive control, using movement, rotation, placing and other manipulations to control the system.
- Physical representations are perceptually coupled to actively mediated digital representations. Both physical and digital representations play the same important role in representation and are co-depended.
- The physical state of interface artifacts partially embodies the digital state of the system. Even with a switched-off system, tokens may represent, with their state, the implied functionality of the system.

In order an interface to be Tangible, It has to embody the following properties [13]:

- Space-multiplex both input and output: This means that each controllable function has a dedicated controller, occupying its own space.
- Allow for a high degree of inter-device concurrency both for input and output.
- Increase the use of strong specialized input devices. Physical artifacts that control the interface must have exclusive, dedicated control area.
- Have spatial-aware computational devices.
- Have high spatial reconfigurability of devices and device context. Physical controllers may not be used at a specific moment during a handle, but their presence in space, keeps reminding their functionality.

Sheiderman identifies three basic properties of direct manipulation interfaces [13]:

- Continuous representation of the object of interest.
- Physical actions or labeled button presses instead of complex syntax.
- Rapid incremental reversible operations whose impact are immediately visible.

Advantages of TUIs [14].

- It encourages two handed interactions.
- Shifts to more specialized, context sensitive input devices;
- Allows for more parallel input specification by the user, thereby improving the expressiveness or the communication capacity with the computer;
- Leverages off of our well developed, everyday skills of prehensile behaviors for physical object manipulations.
- Externalizes traditionally internal computer representations.
- Facilitates interactions by making interface elements more "direct" and more "manipulable" by using physical artifacts.
- Takes advantage of our keen spatial reasoning skills.
- Offers a space multiplex design with a one to one mapping (control – controller).
- Affords multi-person, collaborative use.

TUI systems have already been used successfully in learning processes, concerning narrative or rhetoric programming, molecular biology or chemistry, physics and dynamic systems [16]. There have been an enormous number of applications that take advantages of TUI in order to produce sound or music [17]. They could be separated in two big categories: Table tops and appliances. Tabletops usually use cameras and embodied sensors to input the handles information and screens or projectors to output the digital representation. The interaction takes place at a specific space. Such systems are Audio D-Touch [18], Audiopad [19], Smallfish [20], Jam o-drum [21] and Reactable [1]. Appliances use electronic tokens carrying the digital representation on them and spatial standalone interacting within their parts (e.g. blocklam [22] and audiocubes [23]). Various other application domains [15]:

- Information storage, retrieval, and manipulation.
- Information visualization.
- Modeling and simulation.
- Systems management, configuration, and control.
- Education, entertainment, and programming systems.

1.4 The Reactable

The Reactable is an instrument, which seeks to be collaborative, multiuser, intuitive, giving no manual or instructions, sonically challenging, non-intimidating instrument, learnable and masterable, suitable both for novices and advanced electronic musicians, for home use, studio or live performance of electronic music [24], [25], [26]. Regarding its functionality, Reactable is based on a translucent round table on which, users interact by moving tokens, changing their position and controlling with these actions the topological structure and the parameters of a sound synthesizer.

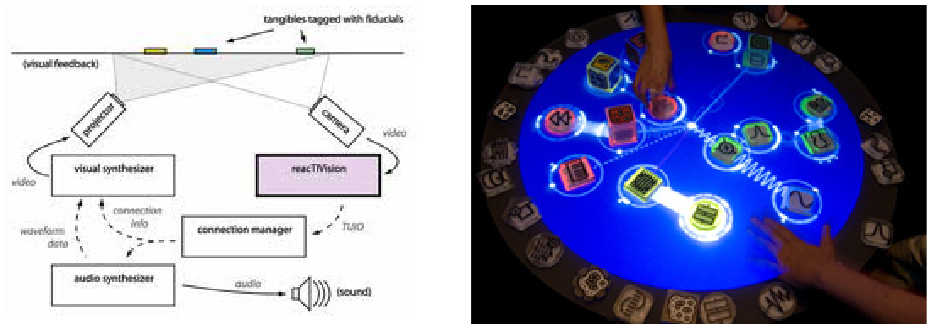

Fig. 1. The Reactable architecture and live action snapshot

Moreover beneath the table, there is a projector dynamically drawing animations on its surface, providing a visual feedback of the state of the synthesizer [24], [26]. Every token brinks a special fiducial marker that is been read by a camera, placed beneath the surface. Software, specially developed for Reactable called “reacTIVision”, reads tokens’ id, orientation, as well as finger placing and gestures, producing information about each token’s position, rotation angle, fingers’ positions and time related sizes, as speed, acceleration etc. [25], [27], [28]. This data is send to connection manager software that will make the appropriate calculations about tokens’ state, based on orientation and proximity, producing control data for the sound and visual feedback [24], [26]. Sound synthesizer is based on modular synthesis principals whereas every token represents a module and their orientation will dynamically set up the desirable connections of these modules [24], [25], [26]. Due to its goals, Reactable is equipped with various sample players, melodic and rhythmic, effects, filters, oscillators and LFOs, sequencers and stuff that will help user to immediately produce music, either his knowing how Reactable works or not [24], [25]. The visual feedback, produced by a visual synthesizer, provides user information about token’s state, sound’s state and modular connections, drawing the formed waveform that "exits" every module. Moreover, it draws graphical controllers, such as sliders, pop-up menus and secondary modules, controlled with fingers [24].

2 Introducing the Spyractable

2.1 Concept and Goals

Getting knowing the Reactable, a simple idea was born. What if all this technology didn't serve the purposes of reactable, an intuitive, ready-to-play organ for electronic music based on modular synthesis, but used to synthesize sounds, an ability that sure Reactable has, but not in a highly sophisticated manner. Would a combination, of computer based modular synthesizer and tangible user interface, offer new possibilities and facilitations to a sound composer? Spyractable was developed to research for this hypothesis. Our goal was to make a computer – based tangible user interface modular synthesizer that would offer to users the opportunity to facilitate sound synthesis in:

- Achieving a target – sound.
- Encourage experimentation.
- Save time.
- Cover user's needs for synthesizing sounds.
- Give clear image about how the sound is being synthesized and what the user did with no complex handles that disorientate composer from synthesis and engross him with button handles and way-finding through confusing menus.

Users and Usage Scenarios: As a user, we define anyone who wants to synthesize sound and is aware of the basic modular synthesis knowledge. We want user to be able to create a sound with various ways, modify a sound as desired in a live time expression situation and correct wrong options as soon as possible, with always be aware of what's happening.

Design and Implementation: In order to have an adequate synthesizer to complete our research it was decided to develop one that will surely implement a modular synthesizer and moreover give a little taste of other synthesis methods, in short mode. It will have various oscillators, filters, effects, LFOs, envelope generators and amplifiers, and could be able to use various synthesis methods. The technology was known, but since we are developing a completely new task, we have to adjust most of the features, keeping the dynamic patching in a modular metaphor by using reactivision's fiducial engine and Reactables architecture. Since this project is done in academic environment and purposes, it was decided to use open source software.

The main program runs in processing, a java based program for graphics that runs in its own compiler [29]. Sound synthesizer was made with pure data, a visual programming language, member of the patcher family [30]. Processing runs the Spyractable. It accommodates the connection manager, receiving messages from reactivision via TUIO library, generates the graphics (visual synthesizer) and reads the pure data file via libpd library.

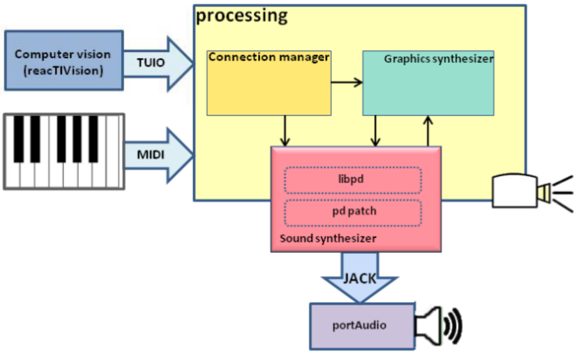

Fig. 2. The Spyractable's software architecture

Spyractable Interface: After draft development and evaluations, we came up with a horizontal interface, where the user stands in front of the appliance surface and puts the tokens in a readable way, developing the modular chain from left to the right. This way he gets the most of the given space and develops his thoughts the way he has learn to present them (according to the west civilianization, but this is easily change).

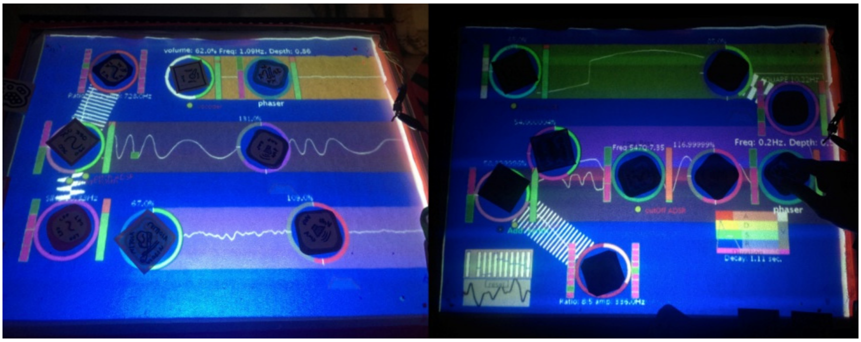

Fig. 3. Spyractable's aspects in action

We have developed 13 tokens including two amplifiers with envelope control, two filters with cut-off frequency envelope control and ability to change filter kind, one time delay effect, one chorus / phaser / chorus+phaser effect, one mixer. Three sample oscillators (violin, trombone and trumpet), a noise oscillator, a microphone input with pitch bend and vocoder, a multi-oscillator that user can choose between sine, saw, triangle, square and their sums wave, pitch envelope and velocity zone control and a sine oscillator with pitch envelope control and an additive synthesizer for forming the waveform by setting fundamental's and overtones' volume and phase (0° or 180°), and velocity zone control. Additional to these, we also made an LFO that can be connected either to wave oscillators or the amplifiers that includes sine, triangle, square and saw waveforms, a master volume and finally a modulator that modulates the sine oscillator's frequency (FM synthesis) with a sine oscillator. The user can choose between the modulation index and the modulator's / carrier's frequency ratio. The pitch is input via midi keyboard.

Hardware: For the hardware we used a 32" Plexiglas surface (4:3) , 45 infrared led lights SFH 485 Osram 880nm , a sony ps3 eye camera without infrared filter, an infrared light pass filter 850nm and a Toshiba TDP45 projector. The software was hosted by a Mac book snow leopard.

Interacting with Spyractable: In order to get a sound, user has to put an oscillator on the surface. Immediately it is connected to the main amplifier, controlled by the master volume. The sound, after is triggered by the midi keyboard controller, is continuous since no volume envelope is applied to shape it. In same case, sample oscillators just play the whole triggered sample till is finished. Next step for the user is to connect an amplifier into the chain. Amplifiers hold the volume ADSR time envelope. In order to make a modular chain, every oscillator draws a color zone, whatever patch (the token accompanied by graphical data forming a module) is in that zone, is dynamically connected in a sound chain, starting with the oscillator at the left and ending at the auxiliary exit at the right side of the screen, connected in turn. The connection between two patches is visualized with the waveform that travels from one to the next module, just like Reactable. LFO and modulator are dynamically connected through proximity rules, to the nearest available patch. All the parameters can be changed either with rotation of the token or with finger handling the side graphical controllers (radio buttons, sliders, switches etc). In order to change one parameter the biggest number of movements, a user may do, in the worst case scenario, is three finger actions, all clearly attached to the controllable patch, saving time and easily clarifying the sound modification. The sound zones may be overlapped. In this case whatever module is in the common zone area accommodates both sound signals derived from its left side.

3 Testing and Evaluation

For the final evaluation of Spyractable, we proceed to usability testing by using two methods. Firstly candidates performed a "Think Aloud" Usability Test [31]. During the test they were given 5 tasks to do. First task was to find how Spyractable works and what each token does. After this we explained to them whatever they didn't find out and proceed to the next tasks. The next three tasks included synthesizing a given sound, with scalable difficulty from task to task. The last one was to make a sound of their own taste. The purpose of these tests was to find how intuitive use Spyractable may have, what usability problems it has, as far as it concerns connectivity, logic and control (both token handling and GUI), how fast, or slow, a sound – goal can be achieved and how it does with free experimentation.

Usability test was supplemented with a semi-structure interview, willing to found out more about what candidates liked or didn't like, what incommoded them, what more did they expected and what surprised them.

Five candidates participated the test, with different level of knowledge in synthesizers (novice to experts), different cultures (analogue devices to complex computer programs) and different focus in synthesis (hobby sound creation to professional sound designers).

Various conclusions were given about the way of use and the behavior Spyractable faced, depending on the categories of users, but as far as it concerns usability problems, most people agreed by finding the same ones.

As far as it concerns logical mistakes and disadvantages, most people didn't like the view of GUI elements or didn't notice some of them at all. All the candidates looked up for the volume envelope to be controlled by the oscillators' patch, even though this is incorrect for the modular logic. Expert users though modulator was for Ring modulation effect, even though they use fm synthesis on VSTs, and many problems were faced with the rotation of patches since when it reached its maximum price it hopped back to the minimum and vice versa.

As far as it concerns usability problems, most people couldn't handle patches on the surface and either they were hiding the GUI elements or had to move them to other positions, sometimes whole of the sound chain. Another similar problem that contributed the first one was the ergonomics of the set-up. Candidates had to either rise from their positions to put a token on the upper space of the screen, or put them at the down side till they couldn't fit. Another serious notice was that most of the candidates were using only one hand to handle them and the other to trigger notes from the keyboard, even though they had alternatives for note triggering. This is probably a matter of habit, because since they were helped with keyboard, they started using both their hands. The third problem was in some cases a though, and in others an incident. What happens if you accidentally step on the surface, displace the tokens or change a GUI given option, moreover during live performance? This mostly had to do with Spyractable's early view that didn't inspire any confidence but on the other hand looked very fragile. Last but not least was the question how it will save a sound, how it will reload it and how the reloaded sound will be controlled? But since we don't come up in design with that matter, we don't really know whether there will be a problem or not.

To answer our assumptions and thoughts, despite the upper problems, Spyractable impressed most of the candidates, willing to fix the problems and expand it with more effects and features. It does shorten synthesis procedure time with fewer steps till the final goal, compared with what candidates used to use. Candidates also claimed that they understand some things they hadn't clear in their mind, and it was much more playful and mind absorbing than the synthesizers they had with much easier manipulation. To end up with we believe Spyractable to enhance creativity, since candidates were truly happy to make their own sounds and took much time for this, used as much patches as possible, even asked for more and impressed by using techniques they didn't have in mind (like the two amplifiers or parallel use of sample oscillator and simple oscillators) and proposed creative ideas to elevate the fan.

4 Future Development and Research

All the conclusions came up with some standards that are:

- It was a brand new experience for all the candidates and were impressed.
- It was a small implementation with the least synthesizer features. This fact made it easier to build an easy to use interface.
- The set up was truly very dreadful to fall apart.

So far TUI looks really helpful with sound synthesis, and most of Spyractable's problem seem to be easily, or not so easily, solved, but if we really want to see if a TUI synthesizer can stand as a commercial product, we have to test it with better hardware, and much more tokens and complicated modules, tested by candidates who are familiar with TUI technology.

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