# ΕΛΛΗΝΙΚΟ ΜΕΣΟΓΕΙΑΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ

**ΣΧΟΛΗ ΜΟΥΣΙΚΗΣ ΚΑΙ ΟΠΤΟΑΚΟΥΣΤΙΚΩΝ ΤΕΧΝΟΛΟΓΙΩΝ**

**Τμήμα Μουσικής Τεχνολογίας και Ακουστικής**


***Πτυχιακή εργασία***

**Βελτίωση της παραδοσιακής αλληλεπίδρασης με το Yamaha DX7, με την χρήση Απτής Επιφάνειας Εργασίας**


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*Βαθμίδα*



*Ρέθυμνο, Μάιος 2022*

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**Τομέας .........**

# *Πτυχιακή Εργασία*

**Enhancing the Yamaha DX7 traditional UI with a Tangible Tabletop Interface**

## *Του/ης*

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*Βαθμίδα*

Εγκρίθηκε από την τριμελή εξεταστική επιτροπή την [Ημερομηνία …η …. ….].

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*Ρέθυμνο, Μάιος 2022*

## Πνευματικά δικαιώματα

## Πρόλογος

Το DX7 της YAMAHA θεωρείται ένα από τα πιο θρυλικά synthesizer της δεκαετίας του 80, που έγινε ευρέως γνωστό τόσο για την πρωτοτυπία στη χρήση της FM synthesis όσο και για τη δυσκολία στον προγραμματισμό των απεριόριστων επιλογών που παρείχε. Σκοπός της παρούσας πτυχιακής εργασίας είναι η βελτίωση της ευχρηστίας του DX7 σε σχέση με τον παραδοσιακό τρόπο αλληλεπίδρασης με χρήση Απτής Επιφάνειας Εργασίας (διαδραστική επιφάνεια απτικής αλληλεπίδρασης), στην οποία εκμεταλλευόμαστε τους δύο βαθμούς ελευθερίας αυτής. Για το σκοπό αυτό αναπτύξαμε κατάλληλη διαδραστική επιφάνεια για την οδήγηση ενός αλγορίθμου που προσομοιάζει τη λειτουργία του DX7.

Στο θεωρητικό μέρος της εργασίας γίνεται ανασκόπηση του synthesizer DX7 από τη σκοπιά της ευχρηστίας, καθώς και των Απτών Επιφανειών Εργασίας από την πλευρά των ηχητικών διαδραστικών εφαρμογών. Ακολουθεί παρουσίαση του λογισμικού για την ηχητική σύνθεση, την αντιστοίχιση παραμέτρων και την οδήγηση της γραφικής ανάδρασης. Τέλος, παραθέτουμε μια σύντομη ποιοτική αξιολόγηση πρώτου προσώπου σχετικά με το επίπεδο ευχρηστίας του διαδραστικού συστήματος, καθώς και κάποιες ιδέες για μελλοντικές επεκτάσεις.

## Abstract

The Yamaha DX7 is considered one of the most legendary synthesizers. It became widely known during the 80s both for its original approach in the use of FM synthesis and for its difficulty in programming the unlimited options it offered. The purpose of this thesis is to improve the usability and interactive possibilities of the original DX7 by using a Tangible Tabletop Interface (TTI) which provides the opportunity to interact with the synthesis engine through a 2-dimensional space. For this purpose, we have developed a suitable interactive surface for driving an algorithm that emulates the operation of the DX7.

The theoretical part of the thesis includes a review of the DX7 focusing on its usability, but also a review of Tangible Tabletop Interfaces with a focus on their affordance, i.e. the potential audio interaction possibilities they offer to a user. What follows is a presentation of how the interactive surface was constructed in hardware, as well as a detailed description of the software that was developed for sound synthesis, parameter mapping and graphical feedback. The thesis concludes with a short first-person qualitative evaluation in terms of usability and some thoughts on future work.

## Acknowledgments

I want to thank my teacher Stella Paschalidou for the assignment of this project and the help she offered. Also, I want to thank my family and my friends for their love and support.

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## List of Abbreviations

**LCD** **L**iquid **C**rystal **D**isplay

**FM** **F**requency **M**odulation

**ADSR** **A**ttack **D**ecay **S**ustain **R**elease

**TTI** **T**angible **T**abletop **I**nterface

**TUI** **T**angible **U**ser **I**nterface

**DI** **D**iffused **I**llumination

**FTIR** **F**rustrated **T**otal **I**nternal **D**eflection

**DSI** **D**iffused **S**urface **I**llumination

**CCD** **C**harge **C**oupled **D**evice

**LFO** **L**ow **F**requency **M**odulation

**UDP** **U**ser **D**atagram **P**rotocol

**UI** **U**ser **I**nterface

# Introduction

Synthesizers have always comprised an important category of musical instruments in many music genres, ranging from pop – rock, to jazz, to traditional and even classical music. They gained great popularity in the late 50s, a period during which electronics progressively became an integral part of the human everyday life. The first types of synthesizers were extremely inaccessible to an average consumer since they occupied the space of a large room. That made them expensive and by no means user-friendly. Over the years, and with the advancement of technology, synthesizers became progressively smaller and accessible to a wider spectrum of musicians and other users. Resulting to a variety of different synthesizers appearing, with production companies competing in creating a more compact, affordable, and easier to use synthesizer, with more realistic sounds, and cheap enough for anyone. Many synthesizers successfully met these requirements, however some—despite their huge popularity—failed in incorporating efficient control interfaces that could address the complexity of multi-parametric interaction. The most notable among these cases has been the legendary Yamaha DX7.

The Yamaha DX7 appeared in 1983 and is considered the first successful digital synthesizer and one of the best-selling synthesizers in history. Incorporating new technologies at the time and with a lower price-tag compared to others, it has made its way as a replacement of antecedent workhorse synthesizers (Lavengood, 2019). It appears that keyboardists all over the world were dazzled by the possibilities the DX7 had to offer, and some of its preset sounds have become staples of the 1980s pop music. Unfortunately, less experienced musicians or users were intimidated by the complexity of the DX7 interface, and it appears that only few have succeeded in mastering all its programming capabilities. The reason was that a vast number of control settings were hidden under complex, multi-layered menus, which could only be accessed in a serial selection manner. Consecutive pressings of buttons aided by a small LCD display with binary representations was the only way to access the numerous control menus and settings of a 6-oscillator Frequency-Modulation algorithm, including controls of 7 ADSR envelopes. Although saving and recalling presets has been proven beneficial, many of these complex adjustments were necessarily made live.

The current project describes an attempt to simplify the interaction paradigm of the DX7 by introducing an interface that allows for a higher-dimensional interaction, to offer an intuitive multiparametric control of the complex DX7 algorithm. With the steep increase of popularity in the use of 2D multi-touch surface interactions, such as those found in smart phones and tablets, Tangible Tabletop Interfaces (TTIs) have been a straightforward choice.

TTIs represent a rapidly growing area of interface technology, based on a horizontal projection surface integrated into a tabletop, in combination with tangible interaction devices, such as styluses, fingers or physical objects (fiducials) positioned on top of a projection surface (Dalsgaard & Halskov, 2012). TTIs use a camera and a projector to read and manipulate data, providing to the user a visual and audio feedback. Such interfaces have a general use, and are often deployed in applications or installations that one often encounters in museums, exhibitions e.t.c.

The main scope of this thesis is to examine whether the use of a TTI can augment the traditional interface of the DX7 and establish a more user-friendly interaction. For this, a tabletop interface is developed that runs an implementation of a DX7 emulating application, named *Synthtable*. The *Synthtable* is developed as an alternative 2-dimensional interface for enhancing the user experience in interacting with the DX7. Its ultimate purpose is to provide a more user-friendly and intuitive interface by allowing a user to play and control the DX7 emulation even without any requirements for programming skills or music education, more specifically aiming at the following:

- Simultaneous multi-parametric control (2-dimensional position of fiducials and fingers)
- Enhanced multi-parametric navigation through graphical feedback
- Faster accessing of parameter controls (by avoiding menus)
- Collaborative music making by multiple users

Potential users include professional musicians and amateurs alike, who favor the distinctive sound of older synthesizers such as the DX7 but are hoping to avoid its programming and interaction complexity.

The thesis is structured in the following way:

Chapter 1 presents general knowledge about the DX7 followed by a detailed presentation of its functions. Furthermore, chapter 1 addresses the general topic of interacting with a Tangible Tabletop Interface, providing a historic background and examples of such interfaces. Finally, detailed instructions on how to create a tabletop interface are also presented.

Chapter 2 hosts the practical part of the thesis, in which the design and implementation of the *Synthtable* interface are presented. Additionally, this chapter opens a discussion on the interaction paradigm this new type of interface offers. A detailed presentation of the *Synthtable* follows, which includes hardware and software components. The chapter closes with a short self evaluation of the *Synthtable*.

Chapter 3 justifies the power of the *Synthtable* as compared to the classic DX7 design, but also poses limitations of the design.

# 1 Literature review

In the current chapter, the complexity of the DX7's interface will be explicated by analyzing each parameter of its algorithm. Detailed information about Tangible Tabletop Interfaces (TTIs) will be also provided, along with instructions on its construction.

## 1.1 The Yamaha DX7

Yamaha DX7 was a legendary synthesizer that made its appearance in the 1980's. It was the first digital synthesizer to be used in studios. Yamaha is estimated to have sold more than 150.000 DX7 synthesizers between 1983-1989. This all-in-one instrument, although monotimbral, could simultaneously play sixteen notes and featured the MIDI protocol (Yamaha Corporation, 1983).


**Figure 1: The Yamaha DX7 (admin@twk., 2018).**

### 1.1.1 Yamaha DX7 user interface and algorithms

DX7 offers two working modes to the user, the Function Mode, and the FM Tone Generator mode. The Function mode enables the direct selection of one of the default 32 algorithms & sounds without the need of further editing. For further editing of the sounds, the user must work in the FM Tone Generator (Yamaha Corporation, 1983).

The FM Tone Generator is a rather complex mode as it enables multilayered editing done only through linear browsing on its menu, thus allowing for one parameter alternation at a time. This makes it difficult to understand and adjust. With only few buttons and a small LCD screen on the surface of the synthesizer available for editing, many users prefer to play the DX7 only with its preset sounds as it is hard to understand how to adjust all these parameters. The poor usability of the FM Tone Generator has been the biggest disadvantage of the instrument (Yamaha synth 40th Anniversary, 2014). According to its manual (Yamaha Corporation, 1983), the DX7 has a 32-voice internal memory, while external cartridges can be plugged in and provide an extra 96 voices, creating a total of 128 voices for instant use by the performer.

### 1.1.2 FM Tone Generator

The DX7 was the first commercial synthesizer that used FM synthesis to create new sounds (Shepard, 2013). FM synthesis stands for Frequency Modulation and is based on the same principle used for transmitting radio signals. In FM radio the carrier is an extremely high "ratio" frequency, and the modulator is the music signal that needs to be broadcast. Thus, the carrier "carries" the modulator signal through air to receiving antennas (Chowning, J., & Bristow, D. 1987). The FM tone generator of the DX7 follows the same principle with the difference that the carrier and the modulator are both audible signals and their frequencies can be almost equal (Yamaha Corporation, 1983).

The first algorithm of the DX7 consists of two carriers and four modulators. Oscillators 1 and 3 are used to function as carriers, while oscillators 2, 4, 5 and 6 are used as modulators. The carrier signal determines the pitch of the note produced and the modulator determines the shape of the waveform produced and thus its timbre (Yamaha Corporation, 1983). Although a carrier and a modulator might look like two separate things, they are essentially the same; DX7 uses an oscillator unit called "operator" that can serve both as a carrier and modulator.

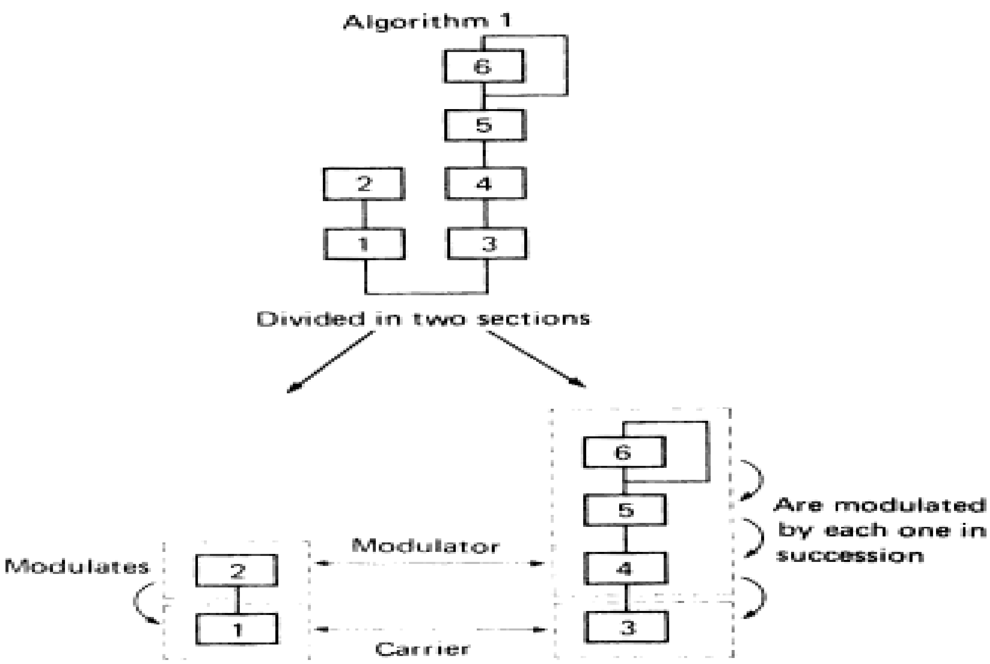


**Figure 2: First algorithm/voice (Yamaha Corporation, 1983).**

The operator consists of three highly important data and according to its values, a different output is produced.

1. **Pitch frequency data**
2. **Modulation data**
3. **Envelope data**

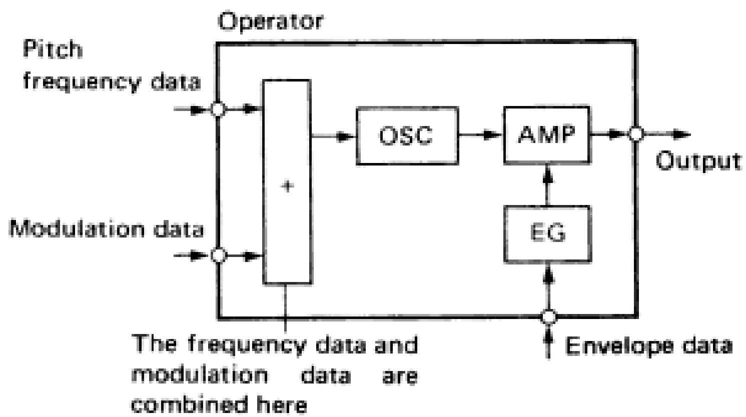


**Figure 3: The operator (Yamaha Corporation, 1983).**

DX7 enables the user to combine several operators and create new sounds from scratch. For example, one can use either the combination of carrier and carrier, or the combination of carrier and modulator. By connecting carrier and modulation operators the user can create new algorithms and voices. To create new voices or alter the existed ones, the user must press the "EDIT" button one the DX7. This provides the user with a wide variety of parameters and settings by which one can change the original/saved sound. These parameters and settings are the following (Yamaha Corporation, 1983):

1. **Edit mode**
2. **Operator on-off/EG copy**
3. **Algorithm**
4. **Feedback (the feedback amount of the 6$^{th}$ oscillator)**
5. **LFO (Low Frequency Oscillator)**
6. **Mod sensitivity**
   - Pitch
   - Amplitude
7. **Oscillator**

   When accessing the oscillator there are several parameters the user can adjust:
   - Mode
   - Sync (Synchronize)
   - Frequency coarse/Frequency fine
   - Detune
8. **Envelope Generator (ADSR)**

- Rate
- Level

9. **Keyboard level scaling**
   - Break point
   - Curve
   - Depth
10. **Keyboard rate scaling**
11. **Operator**
   - Output
12. **Key velocity sensitivity**
13. **Pitch EG**
14. **Key transpose**

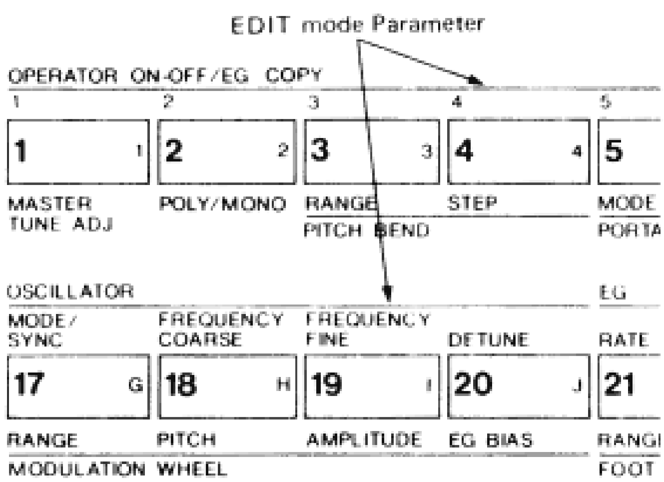


**Figure 4: Altering some of the above parameters of the FM Tone Generator's Edit mode (Yamaha Corporation, 1983)**

## 1.2 Tangible Tabletop Interfaces

To start off the discussion on this topic, a determination of TTIs is worth mentioning: Tangible Tabletop Interfaces “are a subset of Tangible User Interfaces (TUI) because they use computationally augmented physical objects on a tabletop surface” (Xambo,2015). In other word, TTIs typically fuse physical and virtual environments using a camera and a projector to display useful information and data to the user, in other words they rely on a multitouch surface and are controlled through direct input (Xambo, 2015). Interaction in TTIs can be accomplished via finger touch (e.g., single or multitouch input data), by manipulating tangible objects with special markers as input data, or by using both touch and tangible objects (hybrid systems) (ibid).

Tangible Tabletop Interfaces are divided into audio and non-audio ones. The non-audio TTIs track the position and movement of an object on their surface and give visual feedback to the user’s physical input (Xambo, 2015). Examples of such systems are Digital Desk (Wellner, P. 1993), Bricks (Fitzmaurice, et al, 1995), Sensetable (Patten, et al, 2001) and Urp (Underkoffler, J., & Ishii, H. 1999). These systems, as purely graphical interfaces, present several advantages; they enable the user to organize objects in order to solve problems, as in two-handed interaction or collaboration between multiple collocated users (Pangaro et al., 2002). These systems differ from those used in audio interaction because they use sound as feedback and are not intended to manipulate sound. All current TTIs share the same problem; while input occurs through physical manipulation of tangible objects, output gives feedback only in sound and graphical projection on and around the objects. As a result of this, the tangible objects cannot represent the physical manifestations of the information itself and the objects feel like they do not match the movement (ibid).

The audio TTIs are the same as those mentioned above and use the same structure. The only difference between them is that users of these TTIs often manipulate physical artifacts on a tabletop surface to build and modify music or sound. These interfaces enable the user to move objects freely and quickly on the table in real time and change the parameters of the sound that is produced.

> “The design approach in these projects demonstrates ways to visually guide players in understanding the current musical state of the system’’ (van Troyer, 2017:187).

It is considered an innovation in music performance, as the user is now able to play music without possessing any knowledge of it. Music applications or applications that produce sound are one of the oldest and most popular areas for TUIs and have been introduced throughout the millennium with projects like Audiopad (Patten et al., 2002), Gridi sequencer (Shaer et al., 2019), Reactable (Kaltenbrunner, M. 2006) e.t.c.

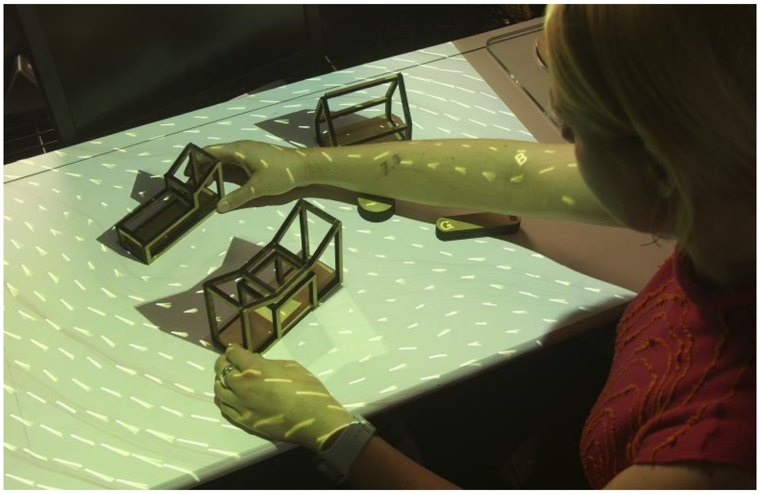

**Figure 5: Urp non-audio interface (Underkoffler, 1999)**

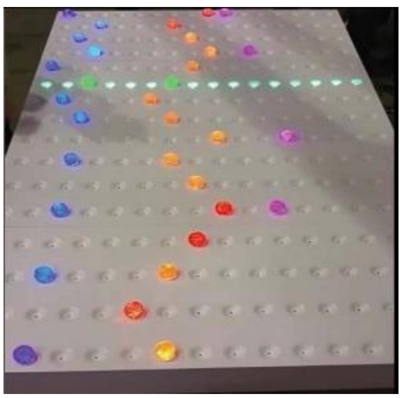

**Figure 6: Gridi sequencer audio interface (Shaer et al., 2019)**

The main part of this thesis is the *Synthtable* which will be analyzed later on, what follows next is a small presentation of the Reactable, on which the *Synthtable* was based on.

### 1.2.1 The Reactable

One of the most known TTIs is the Reactable, which is a novel multi-user electro-acoustic musical instrument. “Several simultaneous performers share complete control over the instrument by moving physical artefacts on the table surface while constructing different audio topologies in a kind of tangible modular synthesizer or graspable flow-controlled programming language” (Kaltenbrunner, et al., 2006). The hardware of the instrument is placed on a round transparent table of a 90cm diameter and height equally. Underneath the table the computer vision system can be found; a camera is placed which continuously analyzes the table surface and tracks where the artifacts are placed (Jordà, S. 2010, April). The tangible objects that users manipulate constitute physical representations of potentiometers to be typically found in classic modular synthesizers; users interact by moving them, changing their position, orientation, or side. With each action a parameter is controlled, and a sound is produced (Xambo, 2015). Furthermore, a short-throw projector is also placed underneath the table and gives visual feedback to the user. The core sensor component of the Reactable is the ReacTIVision, an open-source software that is used for the tracking of fingers and objects on the table. ReacTIVision was designed by Martin Kaltenbrunner and Ross Bencina. Another feature worth mentioning about the Reactable is how the tangible objects interact with the table without any sensors. On one or all the sides of an object there are some unique marker references, similar to barcodes, called fiducials. Fiducials can be read from the camera, identified by the ReacTIVision software and provide useful information, such as position, rotation etc (Kaltenbrunner et al., 2006).

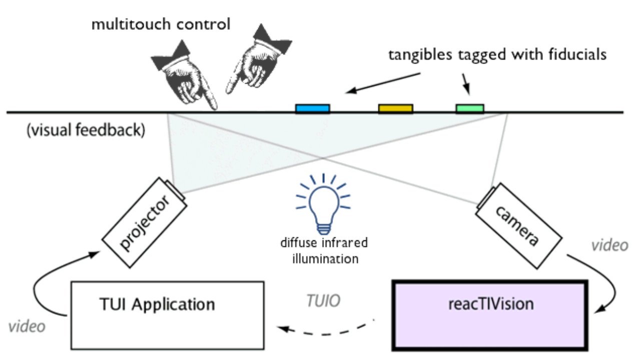


**Figure 7: Installation of Reactable (Kaltenbrunner et al., 2007)**


**Figure 8: Commercial Reactable (Kaltenbrunner et al., 2006)**

The next section explicates construction details for such a tabletop construction.

## 1.3 Table construction

According to Kaltenbrunner (Kaltenbrunner et al., 2007), there are several steps in the construction of a TTI and these will be discussed here in detail. TTIs are used for various purposes, such as music performance, 3D representation, multiple collaboration etc. Although their overall structure is based on a common principle, they may differ on the basis of individual requirements and specificities of installation conditions. When used as a musical instrument, the installation should be portable and easy to assemble and disassemble. When used for public installations (e.g. in museums), the installation must be robust and accessible.

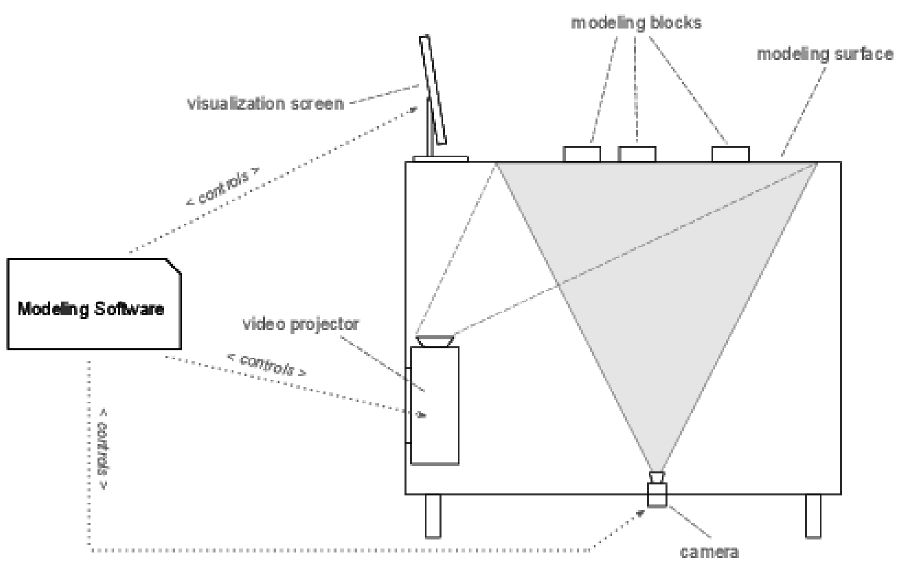


**Figure 9: Basic construction diagram (Kaltenbrunner et al., 2007)**

The individual components that are used for such an interface construction are described below.

### 1.3.1 Frame

A highly important component of the table is the frame. It is the foundation of the whole system that keeps everything in place. For the table-based surfaces the frame needs to be stable and reliable to support the wall covers, the surface and all the other components inside the table. Some other characteristics that must be taken into consideration when building a tabletop interface are the durability of the items used (so they do not break or bend when the table is transported), the easy assembly and disassembly and also the weight, which is of great importance in large constructions. Furthermore, a good suggestion would be to use aluminum as it is cheap, has a large range of structures and is available in various thicknesses and lengths. Aluminum is easy to handle, easy to craft and cut using a metal saw. Using aluminum will also help in mounting the difficult components, such as the projector or the camera (Müller-Tomfelde (Ed.), 2010).

### 1.3.2 Surface

In most cases, and although the most important component of the table is its surface, a simple glass table suffices for building a prototype. It is recommended that the table's surface is semitransparent, using a sanded glass or a Plexiglass with a blurring coating, even without using a projection (Müller-Tomfelde (Ed.), 2010). Achieving a blurring surface is easy and can be achieved by placing an ordinary piece of tracing paper on the table. It is important for the table structure to have a blurry surface because on the transparent surfaces objects can be tracked above the table to a point where the image loses focus and leads to unpredictable detection results. A desirable quality for the table would be for it to be able to track the objects only when they are placed on it and lose them when they are lifted. Furthermore, in order to improve sensor behavior, a semitransparent surface serves as an ideal projection screen for projected visual feedback, which in many cases is needed for a TTI. There are two illumination techniques to choose from (Holzammer et al., 2009): the Diffused Illumination (DI) and the Frustrated Total Internal Reflection (FTIR) technique. Depending on the illumination technique (FTIR or DI) applied, additional layers of different materials may have to be added.

- **Surface materials for DI**

Diffused Illumination (DI) setup requires a material that diffuses the light on the surface. This can be achieved by having the surface itself as a diffuser or by using a transparent surface with an additional diffuser. It is highly recommended to use Plexiglas RP, because it makes a good diffuse surface, rather than simple Plexiglas. Plexiglas RP has small micro-lenses embedded in the acrylic sheet that distribute the light evenly across the surface. There is no visible hotspot to the resulting projected image since the surface smoothens the light (Echtler, F. 2010). Additionally, the gray surface gives a good contrast with natural colors, and the material is scratch resistant, therefore well suited to direct touch interaction (Schöning et al., 2010). As Plexiglas RP might be more expensive, a transparent surface material combined with an additional diffuser can be used as an alternative. In this case a transparent acrylic plate must be used as a sturdy base layer (a common choice is a 5 mm thick plate). In this case, the additional diffuser takes care of the even distribution of the IR light and the visual projections on the surface. The diffuser can be a rear-projection foil or simply tracing paper (ibid). Materials used as a diffuser must allow enough IR light to pass through in order to create a visible reflection on the surface. The diffuser can be applied in front (front DI) or behind the acrylic (rear DI) (Müller-Tomfelde (Ed.), 2010).

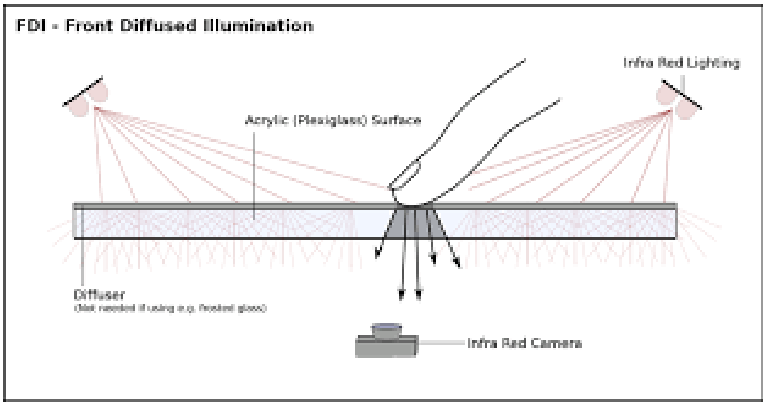


**Figure 10: Front Diffused Illumination (Müller-Tomfelde (Ed.), 2010)**

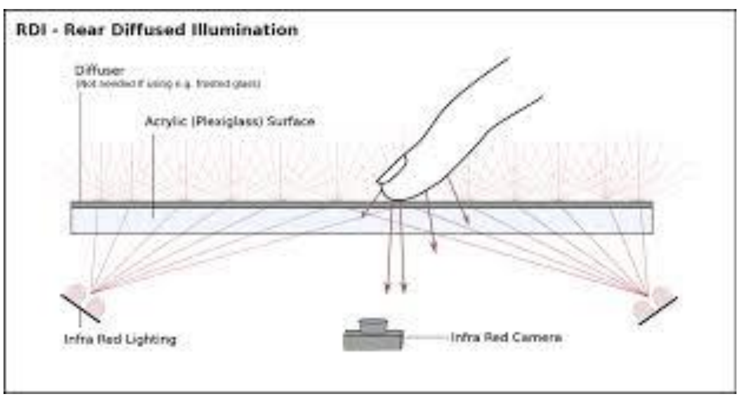


**Figure 11: Rear Diffused Illumination (Müller-Tomfelde (Ed.), 2010)**

If the diffuser is applied in front of the acrylic, the touch experience will be more pleasant since the acrylic itself causes a high surface friction for dragging movements. However, the glossy backside of the acrylic results in hotspots due to the rear-mounted IR illuminators, which interfere with the vision tracking. If the diffuser is applied on the back, the hotspots problems will be decreased since, the IR light will be already diffused before it reaches the surface. A variation of the DI technique is the Diffused Surface Illumination (DSI). DSI uses a transparent acrylic called EndLighten that is a commercial lighting and presentation product. EndLighten has many embedded colorless diffuser particles, which distribute the IR light evenly across the surface.

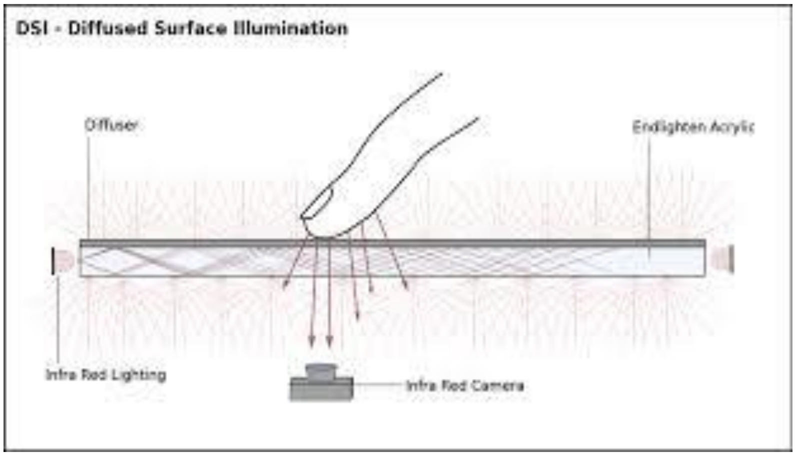


**Figure 12: Diffused Surface Illumination (Müller-Tomfelde (Ed.), 2010)**

DSI uses a standard DI setup but with an FTIR illumination and can be used to track fiducials and finger touch.

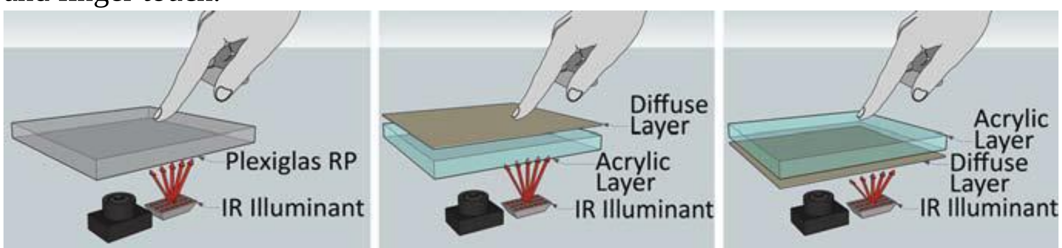


**Figure 13: The simplest DI setup uses the diffuse Plexiglas RP material (left). For Front DI setups, the diffuser is placed on top of the acrylic (middle). Rear DI needs the diffuser beneath the acrylic base layer (right) (Müller-Tomfelde (Ed.), 2010)**

- **Surface materials for FTIR**

The Frustrated Total Internal Reflection (FTIR) technique of tracking user's input is composed of a transparent acrylic plate augmented with a frame of IR-LEDs (Schöning et al., 2010). The acrylic acts as a sturdy base layer that enables the FTIR effect. Also, in FTIR setup a projection layer needs to be applied on top of the acrylic plate, although this will lead to the disadvantage of less sensitivity on the surface and as a result, the users must press harder to activate the FTIR effect (ibid). Additionally, when dragging a finger on the surface, such as in the performance of a motion gesture, friction may reduce the FTIR effect.

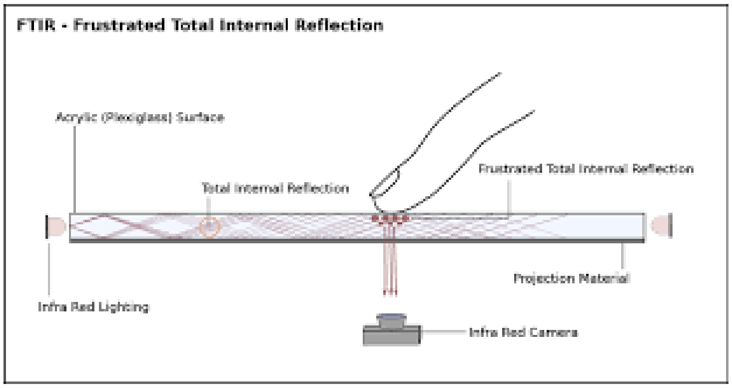


**Figure 14: Frustrated Total Internal Reflection (Müller-Tomfelde (Ed.), 2010)**

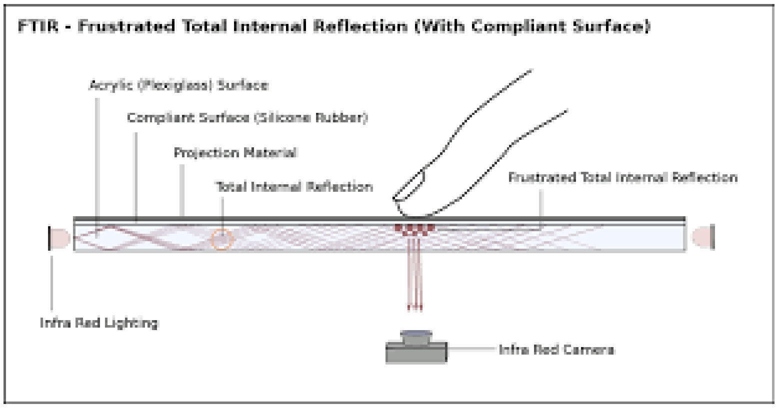


**Figure 15: FTIR (With compliant surface) (Müller-Tomfelde (Ed.), 2010)**

To overcome this problem, many people use an additional layer (compliant surface layer) on top of the polycarbonate material to improve the sensitivity of the surface. The extra materials used for this purpose are usually soft and transparent and placed between the polycarbonate sheet and the projection screen. In FTIR setups it is crucial to have the right materials, otherwise this may lead to problems with the surface. Such problems can be either the continuous triggering of the FTIR effect, even when nothing touches the surface, or that the material does not set enough FTIR. Easily available materials come in the form of SORTA-ClearTM 40 and ELASTOSIL R _ RT 601 silicone, both materials being relatively hard (Hardness Shore A>40), non-tacky and very clear (Müller-Tomfelde (Ed.), 2010). Once hardened, both silicone layers can easily be removed from and re-attached to the polycarbonate surface; the difficult part is to pour the silicone evenly on the surface. ELASTOSIL R _ RT 601 is less viscous and hence easier to pour, resulting in fewer bubbles in the vulcanized layer (ibid). An alternative to silicone could be a thin layer of latex which is both easier to handle and cheaper, too. For the latex to work, it must be combined with the projection later by establishing an air gap between the latex and the polycarbonate base plate. Finally, when it comes to FTIR it is important to know that it is only suitable as a multitouch screen, since it cannot recognize fiducials (Kaltenbrunner & Bencina, 2007).

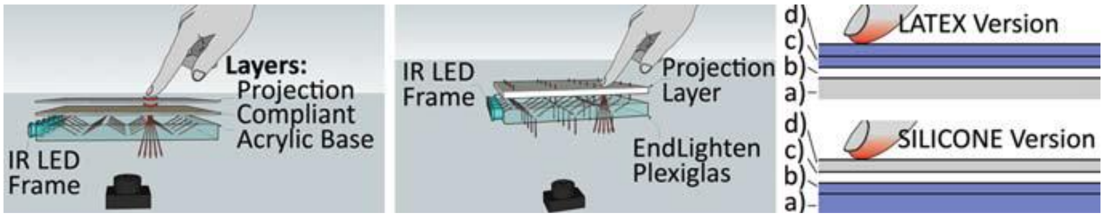


**Figure 16: The EndLighten Plexiglas distributes the IR light from the LED frame across the surface. The three layers needed to track the finger touches. The acrylic plate is covered with a compliant surface layer and a diffuse projection layer on top (Müller-Tomfelde (Ed.), 2010).**

### 1.3.3 Camera and lens

As for the camera part, it is possible to use any kind of camera and lens. Most USB or FireWire webcams with a resolution of 640x480 at 30fps will be sufficient. However, for larger tables it is better to use industrial grade USB2 or FireWire cameras that provide higher resolutions and frame rates. Cameras like DV or video cameras must support full frame mode in order to be used or else, interlaced video signal will completely destroy the structure of fiducial symbols in motion. Another important thing when constructing a table interface, is the computer vision system, in which, the overall recognition performance depends strongly on the source image quality. Image quality is a result of many factors, including the camera sensor, the lens quality and lens settings. Cameras with CCD sensors provide better image quality than those with CMOS sensors. Far preferable are cameras with a replacement lens part. Wide-angle lenses are better used to decrease the minimum distance on a large surface, while the necessary focal length can be deduced by the sensor size, the distance to the surface and the diameter of the viewable surface area (Kaltenbrunner, 2007).

Attention must be given to some consumer wide-angle lenses not focusing across the full viewing area and as a result tracking performance presenting problems. To achieve a high image quality the lens needs to be focused correctly. To do so, an easy way is to fully open the iris of the lens and then try to achieve the best possible focus. Then, the iris can be slowly closed until the image is perfectly sharp or in the best possible quality. Additionally, the camera shutter speed must be fast enough to avoid motion blur because long exposure time will cause blurry images of the moving fiducials, making them difficult or even impossible to recognize. Because of the narrower iris and the shutter speed, less light reaches the sensor and this must be equilibrated with stronger illumination (Steger et al,. 2018). Another way to correct the low lighting is to slightly increase gain, although too much gain will lead to image distortion. (Kaltenbrunner & Bencina, 2007).

**Figure 17: Firewire Camera (vision, M., 2015)**


**Figure 18: Camera lens (Marshall Electronics, 2021).**

### 1.3.4 Illumination

When using a camera-projector system the two visual components need to operate in different spectral bands so that they do not interfere with each other; the projector must work in the visible range of the human eye in order for it to be visually recognized as graphical feedback by the user, while leaving space only in the infrared (IR) spectrum range for the camera to function in recognizing and tracking the fiducials. CCD camera sensors are perfectly sensitive to infrared light, but most of the time they have a factory-positioned IR filter to protect them, which needs to be manually removed from the sensor housing or the lens (Kaltenbrunner & Bencina, 2007).

Furthermore, the table needs to be illuminated with strong and diffused IR light that is invisible to the human eye, so that it does not interfere with the projection. Some recommendations for light sources are IR LED arrays which come in different intensities or halogen lights, which produce a lot of infrared illumination but need the addition of a passive IR filter, to ensure that the projected image does not overlay and interfere with fiducial symbols. This IR filter needs to be placed in the camera to block the projection’s light. If there is no projection on the installation, then the camera can simply operate in the visual spectrum, making things easier.

Both FTIR and DI setups require an infrared light source. To achieve the right infrared illumination can be challenging and requires the knowledge of both techniques of illuminating a surface, but it also requires different types of IR LEDs that are available commercially. For the surface illumination almost all the IR-based LEDs can be used. The most two commonly used are Osram SFH4250 (SMD) and Osram SFH485 (5 mm). SMD and standard LED lights are equal when it comes to which is more appropriate as they have different installations so there are several factors that must be considered to choose one of them. One major problem for both FTIR and IR systems is their sensitivity to ambient IR light from the external environment. This can be solved by adding a small electronic circuit to the set-up, which supplies short high-current pulses instead of a continuous low current (Müller-Tomfelde (Eds.), 2010).

### 1.3.5 Mirrors and lens distortion

When using a camera or a projector that do not have wide enough angle, one can place mirrors into the table that help achieve a larger active surface with lower table height. Unfortunately, mirrors and wide-angle lenses often produce distorted images to the camera and the projector. For this reason, there must be a calibration system that checks the image and corrects these distortion errors. In the case of projection, the image needs to be pre-distorted, by placing the image onto a virtual surface as a texture, so that it appears straight on the table surface. This becomes possible when using the reacTIVision's built in calibration (Kaltenbrunner & Bencina, 2007).

The information just presented, which is based on work by Kaltenbrunner and Fitzmaurice, forms the ideal way to set up a tabletop tangible interface. It is highly recommended for someone to follow these steps, but it does not need to be considered essential. There are a number of variations in placing the camera, the projector, and the lights according to one's needs and set requirements. The table could be open or closed, big or small, appropriate for music composition or for solving problems; there are no boundaries when it comes to TTI.

### 1.3.6 Computer and Hardware

For the computing part and the rest of the hardware, standard components can be used. For example, a modern dual-core computer will be more than capable to operate the visual tracking and feedback and the whole tangible interface application of the system. If there are autonomous setups on the table, a laptop or a small PC might do the job and keep everything portable and fitted in the box. When it comes to the projector, it is usually placed underneath the table and points at a mirror on the bottom edge of the table, thus the most important features are the position of the projector, the lights, and the wide-angle lens. It is known that projectors can produce a considerable amount of heat, which could pose a problem to the setup. In order to deal with this, some type of appropriate ventilation must be installed inside the box to prevent it from overheating (Kaltenbrunner & Bencina, 2007).

### 1.3.7 Tangibles (fiducials)

For the tangible objects that are to be placed on the table, almost anything, from wood, plastic, everyday objects and artifacts, or even fruits and vegetables, can be easily turned into trackable tangible interface components. This can be made possible by placing a fiducial marker on their bottom side, i.e. the side that touches the table. The fiducial symbols can be printed on any laser printer on white paper and then be placed on an object. Gray recycled paper is not preferred as it has the tendency to degrade symbol contrast. Furthermore, there are some inkjet inks that are invisible to infrared light and thus are not to be used in IR illumination setups, although such inks can be used to write tips to the user and stay invisible to the computer without interfering with the application. A way to protect the fiducial symbols that are printed on the paper, from scratches or color loss, is to coat them with a transparent adhesive foil. This way the symbols will also be clean, and no dirt will interfere with the computer vision system (Kaltenbrunner & Bencina, 2007).

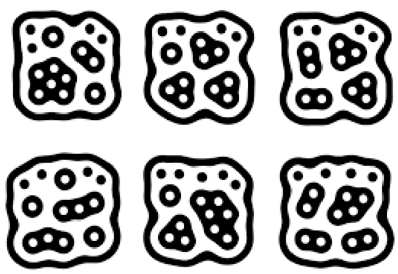

**Figure 19: Fiducial representation (Kaltenbrunner & Bencina, 2007)**

When using TTIs the possibilities are literally endless. *Synthtable* is our own implementation, which—as already explained—aims to serve the purpose of easing the control of a DX7 synthesizer and is presented in detail in the next section.

# 2 Introducing the *Synthtable*

The chapter provides details on the type of interactions this design affords, its intended target group, the software and hardware components it entails, a discussion on usability aspects, and finally a short qualitative self-evaluation, which will then naturally lead to the final chapter for discussion and conclusions.

For this thesis, we developed an interactive surface called *Synthtable*. The *Synthtable* implements the Yamaha DX7's FM synthesis and some other important parameters of the produced sound (e.g. ADSR time envelope, frequency fine and coarse tuning). It is based on the Reactable architecture and uses the ReacTIVision fiducial engine. *Synthtable* consists of a simple table (frame), a Plexiglas surface (called the appliance surface), IR illumination, a camera and a short-throw projector, as well as a MIDI keyboard and a number of fiducials (16). The MIDI keyboard was maintained as a way to control the pitch of the produced notes as in a DX7, while fiducials placed on the surface were programmed to alter various parameters of the DX7 algorithm.

The user will normally stand in front of the *Synthtable* frame (preferrably the MIDI-keyboard side) and place the fiducials on the appliance surface. The appliance surface includes graphical feedback projected in response to their position and rotation angle. Standing in front of the frame, the user can play on the MIDI keyboard while having instant access to the appliance surface enabling him to place the fiducials fast and accurately. Other users can also interact but without the guidance of the graphics, as these are only readable from the main user's standpoint, i.e the musician standing in front of the keyboard.

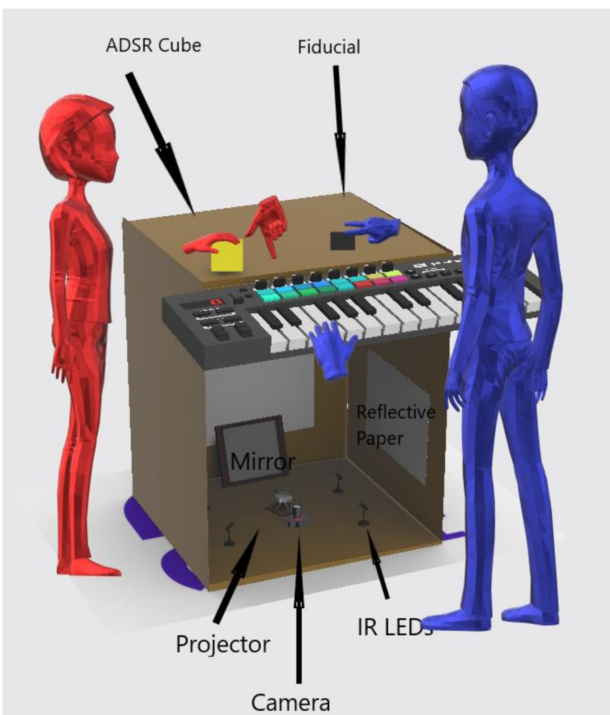


**Figure 20: *Synthtable* representation**

### 2.1.1 Interacting with the *Synthtable*

To start audio, Fiducial 0 (ON/OFF) must be first placed on the table. The master volume will then take a value of 50% and by hitting a note on the MIDI keyboard, the user can further adjust the pitch. When starting the application, the audio engine starts with a simple sine wave. If the user wants to alter the timbre of the sound, one or both Carrier Fiducials must be placed on the surface. Rotating a carrier fiducial, alters the harmonicity ratio of the sound produced. Also, moving a Carrier fiducial on the 2-dimensional space (X-axis and Y-axis) of the surface allows one to adjust the oscillator's frequency in a fine or coarse way accordingly. Similarly, the user can adjust the modulators of the two Carriers. It is important to know that for the modulators to be heard, the Carrier to which they correspond must have harmonicity ratio above 1. The output of the 6 oscillators is controlled by the ADSR cube, which allows for a different envelope to be mapped to each of the 6 oscillators by placing each of the 6 sides of the cube (6 different fiducials) to face downwards. For each of the envelopes, 3 fingers (index, middle, ring) must also be placed on the surface, which control the 3 middle points of an ADSR (the white dots of the ADSR in Figure 21); index finger for the peak amplitude and its point in time, middle finger for the amplitude and point in time at which the sustain parts starts, and ringer finger for the point in time the release begins). Thus, Attack is controlled by the index, Decay and Sustain by the index and middle and all three fingers together control the Release. The user must also be aware that when trying to change a parameter that needs more than one fingers, inevitably all the previous parameters will be altered too, for example when changing the Sustain level that needs 2 fingers, the Attack and Decay will also take different values. Graphical feedback for the ADSR was used to help guide the user in controlling envelopes. This ADSR interaction works both for the main ADSR Fiducial (Fiducial 1) and the ADSR Cube Fiducials (Fiducials 2-7). Furthermore, the design enables one to alter 2 ADSRs together, by placing the main ADSR and one of the cube-ADSR on the surface each time. The L.F.O.s of the 2 carriers can be also adjusted with a separate fiducial by the user, its x and y coordinate for the RATE (speed) of each L.F.O. respectively. Finally, the amount of feedback of the 6$^{th}$ oscillator in the DX7 algorithm can be also adjusted by the user by rotating Fiducial no. 15 ( the so-called Feeback Fiducial) to the left or right.

Simple graphics following the movement of the objects placed on the surface along with the values of parameters that are being manipulated in real-time are used as a visual feedback to assist the user in manipulating the DX7 algorithm. Although every fiducial has a tag (name) that is printed directly on the fiducial and is thus readable by the user, it is also marked in the graphical Feeback with a different color according to the category it belongs to; a purple square for ADSR fiducials, a yellow square for the oscillator fiducials, and a red square for the L.F.O and Feedback (see Figure 21). Finally, a standard ADSR function is projected for each ADSR fiducial placed on the surface.

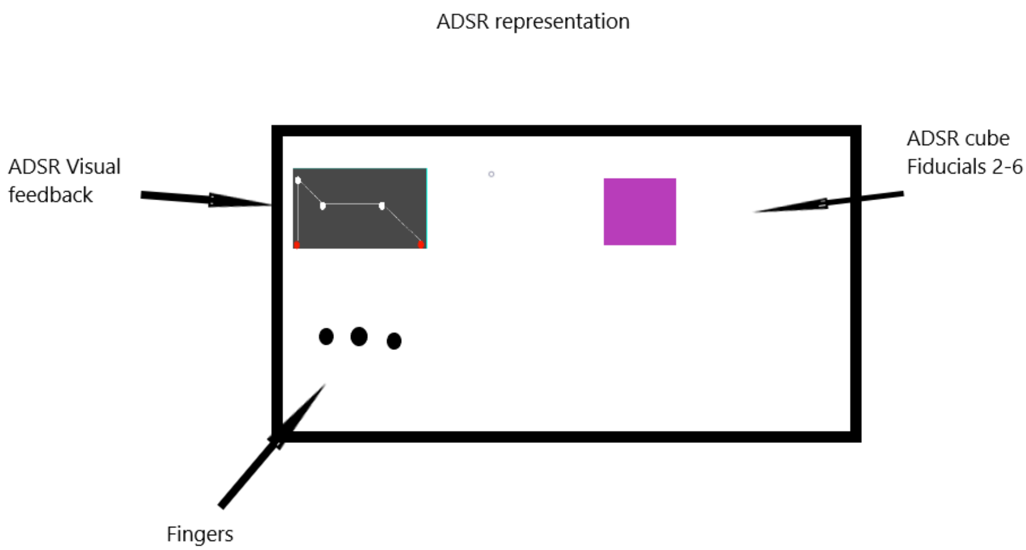


**Figure 21: *Synthtable*'s ADSR representation**

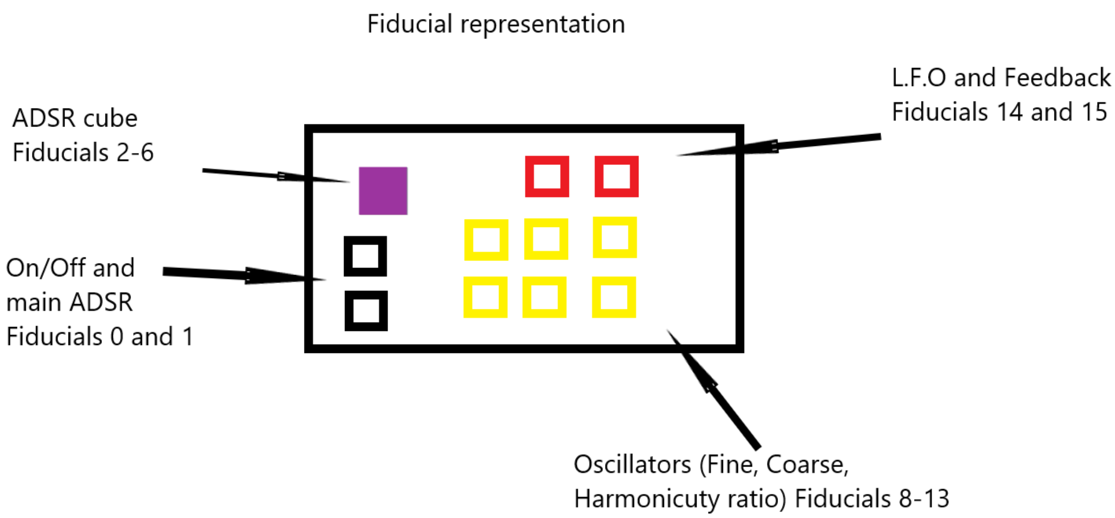


**Figure 22: Synthable's fiducial and finger representation**

### 2.1.2 Parameter mapping

It should be noted here that out of the 32 algorithms of the DX7—which, despite their different structures, all share the same type of parameters—only one was implemented in the *Synthtable* and was used as a ‘proof of concept’. Additionally, out of the 14 parameters of the DX7 FM-Tone Generator, which are controlled by a user in manipulating new sounds, only the most important were used. These were the parameters that had the most audible effect on the sound produced and they are the following along with their corresponding settings:

1. **Operator on-off/EG copy**
2. **Feedback (the feedback amount of the 6th oscillator)**
3. **LFO (Low Frequency Oscillator)**
4. **Mod sensitivity**

- Pitch

5. **Oscillator**
    - Mode
    - Frequency coarse/Frequency fine
6. **Envelope Generator (ADSR)**

- Rate
- Level

Fiducials range from 0-15 and are used to manipulate the 6 sound generators we saw in Figure 2. The fiducials are glued on square cardboard pieces covered with transparent tape.

Fiducial 0 is the one used as an ON/OFF switch of the whole application.

Fiducial 1 is used to control the main ADSR of the entire sound engine in combination with the finger touch.

Fiducials 2-7 are also used to control the ADSR but separately for each sound generator. These 6 fiducials are placed on a cardboard cube, one on each side. The reason for this is to have easy access and control of all the ADSRs but only one at a time.

Fiducials 8-13 are used to manipulate the fine (0-99), coarse (0-31) and harmonicity ratio (0-99) of each generator. These fiducials are separated from each other so the user can manipulate one or many voices simultaneously. To manipulate fine, the fiducial must move on the X axis, respectively coarse will be on the Y axis, while harmonicity ratio can be manipulated by rotating the fiducial clockwise or anticlockwise.

Fiducial 14 triggers the L.F.O (0-99) effect of the application. There are two L.F.Os, one for each carrier. The L.F.O of carrier 1 is placed on the X axis and the L.F.O of carrier 2 on the Y axis.

Fiducial 15 manipulates the feedback (0-7) of the last oscillator (modulator 6, Figure 2), moving on the X axis alters the amount of dry signal while moving on the Y axis the amount of wet signal, accordingly.

The values of the fine, coarse, harmonicity ratio, L.F.O and feedback are the same as those presented in the DX7 menu.

A list of all numbered fiducials, their corresponding mode of interaction as well as their functionality follows:

| id | Functionality | X axis | Y axis | Rotation | Fingers |
|---|---|---|---|---|---|
| **Fiducial 0** | ON/OFF<br>Master Volume | | | | |
| **Fiducial 1** | ON/OFF<br>Main ADSR 1 | | | | **Attack**: Index<br>**Decay**: Index<br>**Sustain**: Index, Middle<br>**Release**: Index, Middle, Ring |
| **Fiducial 2** | ON/OFF<br>ADSR 2 | | | Volume<br>Carrier 1 | **Attack**: Index<br>**Decay**: Index<br>**Sustain**: Index, Middle<br>**Release**: Index, Middle, Ring |
| **Fiducial 3** | ON/OFF<br>ADSR 3 | | | Volume<br>Modulator 1 | **Attack**: Index<br>**Decay**: Index<br>**Sustain**: Index, Middle<br>**Release**: Index, Middle, Ring |
| **Fiducial 4** | ON/OFF<br>ADSR 4 | | | Volume<br>Carrier 2 | **Attack**: Index<br>**Decay**: Index<br>**Sustain**: Index, Middle<br>**Release**: Index, Middle, Ring |
| **Fiducial 5** | ON/OFF<br>ADSR 5 | | | Volume<br>Modulator 2 | **Attack**: Index<br>**Decay**: Index<br>**Sustain**: Index, Middle<br>**Release**: Index, Middle, Ring |

| | | | | | |
|---|---|---|---|---|---|
| **Fiducial 6** | ON/OFF<br><br>ADSR 6 | | | Volume<br><br>Modulator 3 | **Attack**: Index<br><br>**Decay**: Index<br><br>**Sustain**: Index, Middle<br><br>**Release**: Index, Middle, Ring |
| **Fiducial 7** | ON/OFF<br><br>ADSR 7 | | | Volume<br><br>Modulator 4 | **Attack**: Index<br><br>**Decay**: Index<br><br>**Sustain**: Index, Middle<br><br>**Release**: Index, Middle, Ring |
| **Fiducial 8** | ON/OFF<br><br>Carrier 1 | Fine | Coarse | Harmonicity Ratio | |
| **Fiducial 9** | ON/OFF Modulator 1 | Fine | Coarse | Harmonicity Ratio | |
| **Fiducial 10** | ON/OFF Carrier 2 | Fine | Coarse | Harmonicity Ratio | |
| **Fiducial 11** | ON/OFF Modulator 2 | Fine | Coarse | Harmonicity Ratio | |
| **Fiducial 12** | ON/OFF Modulator 3 | Fine | Coarse | Harmonicity Ratio | |
| **Fiducial 13** | ON/OFF Modulator 4 | Fine | Coarse | Harmonicity Ratio | |
| **Fiducial 14** | ON/OFF Carrier L.F.O Carrier 1 L.F.O Carrier 2 | Carrier 1 L.F.O | Carrier 2 L.F.O | | |
| **Fiducial 15** | ON/OFF Feedback Oscillator 6 | | | Feedback | |

Table 1: Fiducial-parameter mapping

## 2.2 Software

The application of *Synthtable* consists of three parts: the reading of gestural data, the sound design, and the graphics design. The reading of gestural data is undertaken by ReacTIVision, which reads the position of fingers and fiducials on the surface. These are sent via the UDP protocol to the sound generator of the MaxMsp patch. TuioClient in MaxMsp takes care of decoding the data and sends them to various sound parameters of the MaxMsp patch. The same data is simultaneously sent via the UDP protocol to vvvv, a programming environment which takes care of real-time graphical feedback, where data are used to control various parameters of the graphics generator.

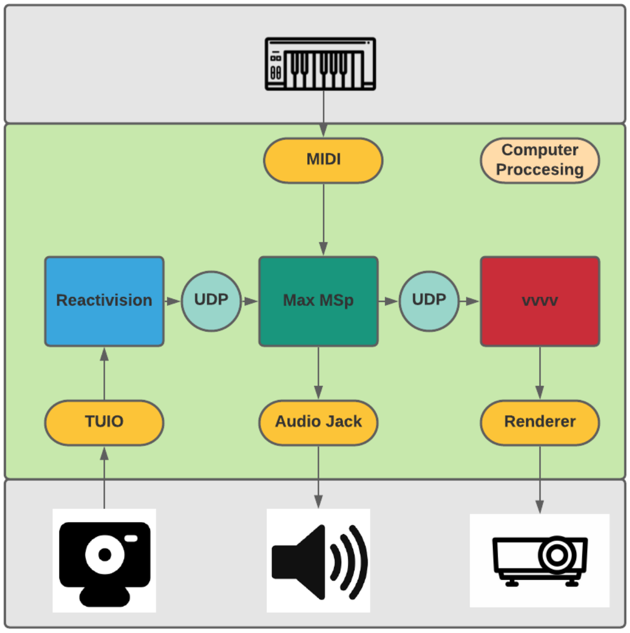


**Figure 22:** ***Synthtable*** **software architecture**

### 2.2.1 ReacTIVision

As already mentioned, ReacTIVision is an open source, cross-platform computer visual framework for the fast and robust tracking of fiducial markers attached onto physical objects, as well as for multi-touch finger tracking. ReacTIVision is the most important component in the application as it reads all the data and converts it into numbers that we can manipulate. When an object (fiducial) is placed on the table it is monitored by the camera which sends data to ReacTIVision.

**Fiducials on table**

For each fiducial, the ReacTIVision receives the position of 10 numbers and presents them in a row from left to right. From these 10 numbers, the first 5 are used. The last 5 numbers are the acceleration of numbers 1-5 and are not useful to the setup we create.

Number 1: Session id (how many times the same fiducial is placed on the table)

Number 2: Fiducial id (the number of the fiducial is used)

Number 3: X axis (position of the fiducial on the X axis)

Number 4: Y axis (position of the fiducial on the Y axis)

Number 5: Rotation

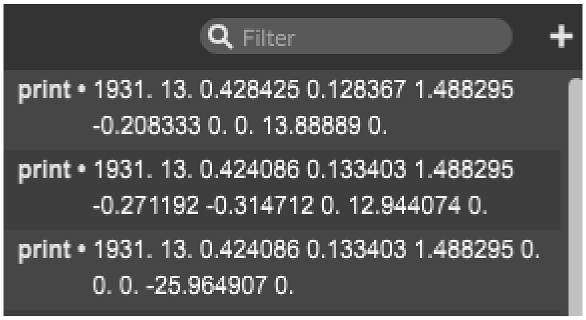


**Table 2: Max Msp fiducial numbering**

When a finger is placed on the table ReacTIVision reads 6 numbers. The first 3 will be used. The last 3 numbers are accelerations and will not be used for this setup.

Number 1: Finger amount id (how many fingers are on the table; one finger is 0)

Number 2: X axis (position of the finger on the X axis)

Number 3: Y axis (position of the finger on the X axis)

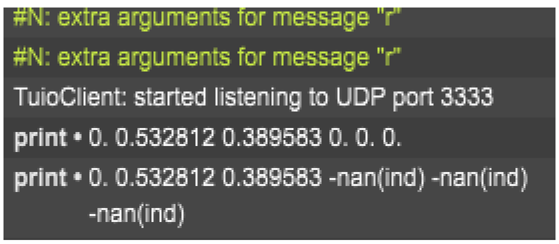


**Table 3: Max Msp finger numbering**

This data is sent to Max Msp via UDP in port 3333 and is then translated into numbers via an object called TuioClient. After being converted to numbers, the data can be manipulated and placed on objects inside Max Msp and vvvv that create sound and graphics.

### 2.2.2 Max Msp

The audio engine of the *Synthtable* was implemented in a MaxMsp patch. The MaxMsp environment was also used to monitor all incoming data. The algorithm made use of two types of data: a) MIDI data from the MIDI keyboard and b) ReacTIVision data from the camera/TUIO. MIDI data is directly received over USB in the Max Msp, while for the ReacTIVision data the TuioClient object is used, that decodes messages from ReacTIVision and displays them as numbers. All types of data are then mapped onto audio parameters, such as pitch, audio levels, ADSR settings, L.F.O. parameters etc. Finally, all data is further sent out from Max Msp to vvvv over UDP for driving the graphical feedback in real-time.

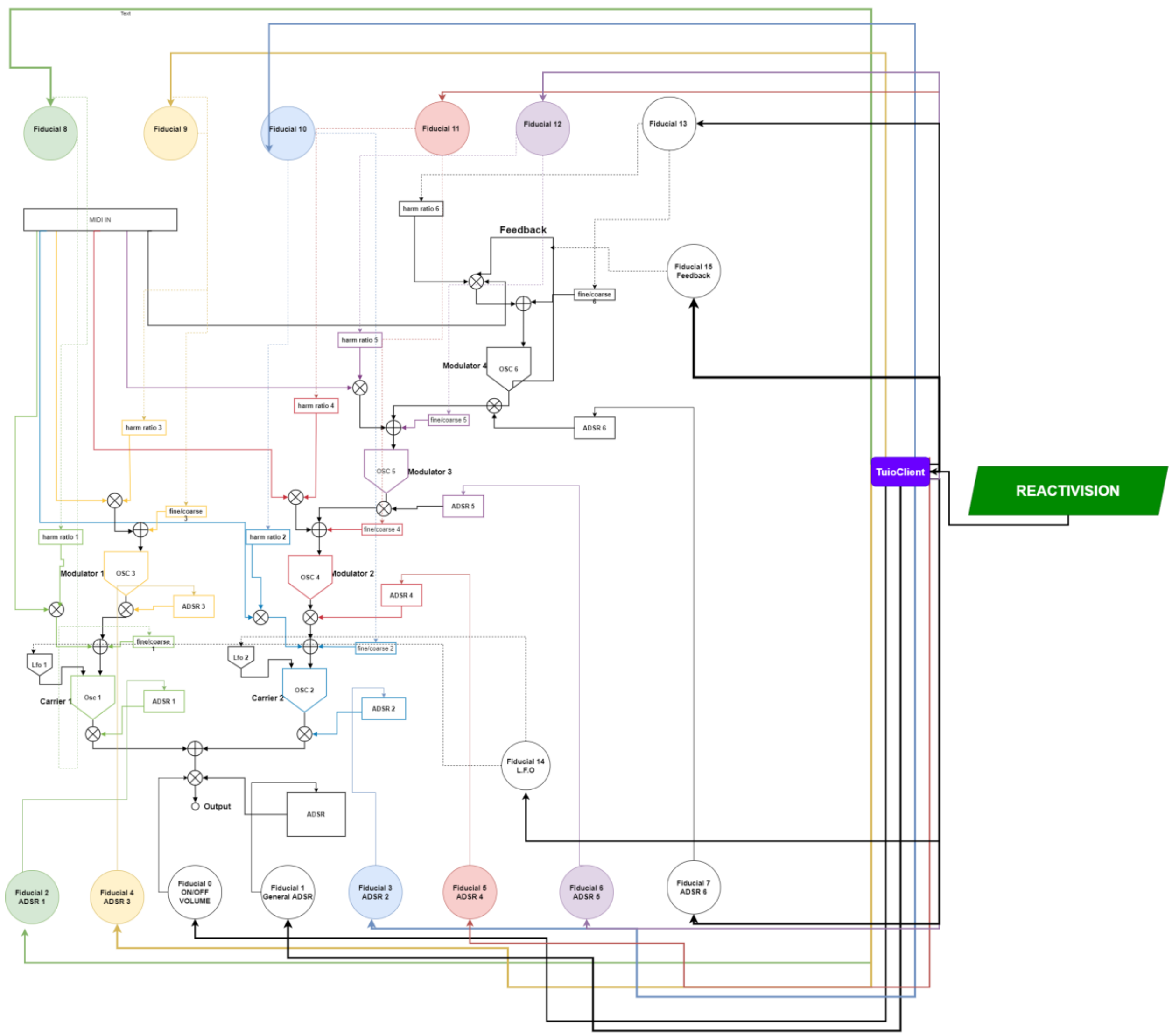


**Figure 23: Max Msp application diagram**

### 2.2.3 vvvv

Vvvv is “a hybrid visual/textual live-programming environment for easy prototyping and development. It is designed to facilitate the handling of large media environments with physical interfaces, real-time motion graphics, audio and video that can interact with many users simultaneously” (Joreg 2018). vvvv is the program used to design the graphic feedback of the *Synthtable* application.

vvvv receives data from Max Msp using the UDP protocol. Parameter values are then displayed next to the objects and their projected graphics, which appear as soon as a fiducial is placed on the surface and are created in vvvv for this purpose.

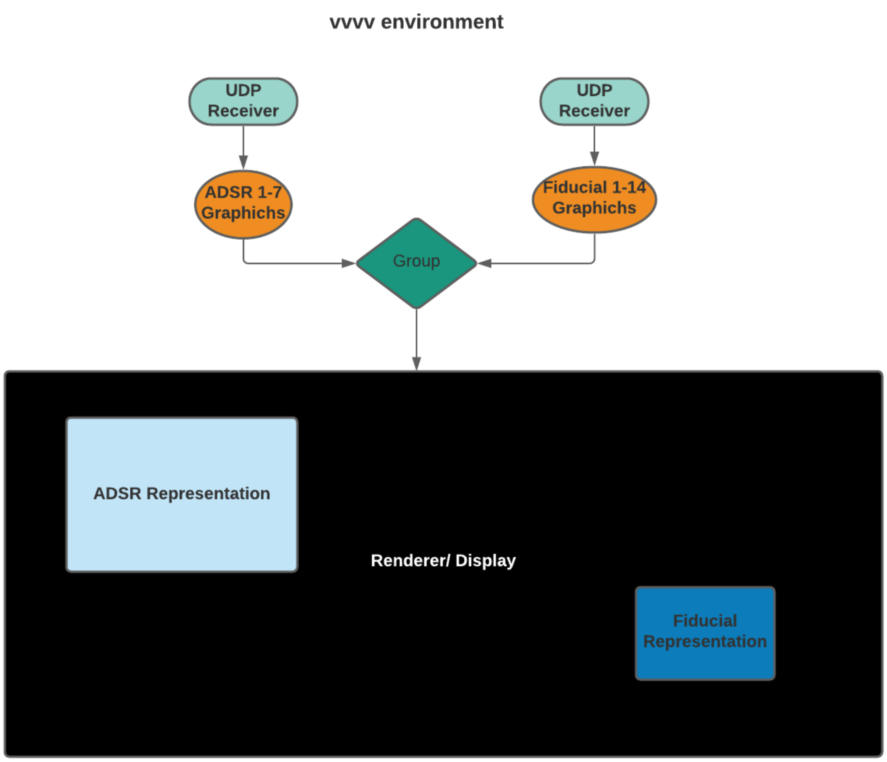


**Figure 24: VVVV graphics connection**

## 2.3 Hardware

The *Synthtable* consists of several hardware components, we tried to use materials that can be easily found in everyday life, as we did not have the luxury to use expensive specialized equipment. A list of all the hardware was used follows next.

### 2.3.1 Frame

The Frame of the table is one of the most important components of the *Synthtable*. It must be stable and easy to construct. For this project, an old TV furniture made of wood was used as a frame. It is heavy, robust and has the precise dimensions required.

The exact dimensions are:

Length: 630mm

Width: 400mm

Height: 970mm

Using a wooden frame was quite exhausting since it was required to use screws to mount everything. As a result, the components had to be screwed and unscrewed several times until the perfect spot for each one was found.

**Figure 25: Interface frame**

### 2.3.2 Surface

At the beginning of this project, the idea was to use the DSI illumination mentioned in Chapter 1, which uses a special kind of plexiglass called EndLighten. Unfortunately, the EndLighten plexiglass was out of stock all around the world and some last pieces were quite expensive for the thesis budget. This led to the choice of the DI illumination setup that needs a simple plexiglass that can be found in every acrylic shop. The dimensions of the plexiglass used in this project are:

Length: 700mm

Width: 500mm

Height: 8mm

This Plexiglass does not fit in the frame, and just sits on it. This happened on purpose as it is planned to use it for a more appropriate frame in the future. In order to diffuse the illumination light, the Front DI technique was used, by placing a tracing paper on the surface of the plexiglass. In conclusion, the setup was not perfect and thus the camera could read some lighting hotspots that fortunately did not intervene to the camera’s readings.

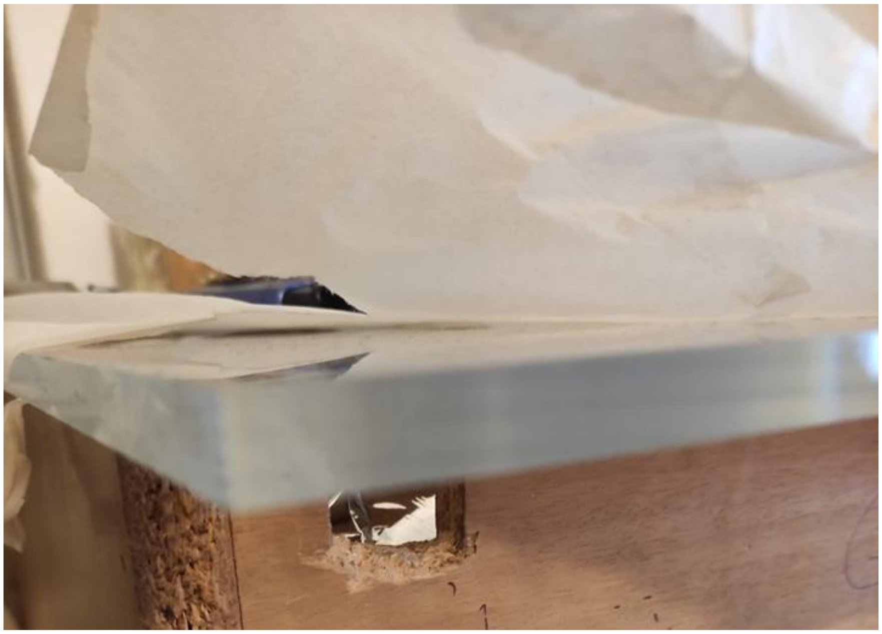

**Figure 26: Plexiglas surface**

**Figure 27: Surface with tracing paper**

### 2.3.3 Camera and Lens

Four different cameras were tested until it was decided that the only way to overcome both the image quality and the tracking problems, was to use a firewire camera. One camera was purchased from China. It is an industrial camera from a company named ELP that was mentioned in reacTIVision's site. The specifications of the camera are:

| | | | |
|---|---|---|---|
| Sensor | 1/2.7" CMOS OV2710 | | |
| Lens size | 2.8-12mm(manual) | | |
| Max. Resolution | 1920X1080 | | |
| Picture format | MJPEG | | |
| USB Protocal | USB2.0 HS/FS, USB1.1 FS | | |
| Support free driver | USB Video Class(UVC)1.1 | | |
| Auto exposure AEC | Support | | |
| Auto white blance AEB | Support | | |
| Frame rate | 1920 (H) x 1080 (V) pixels | MJPEG 30fps | YUY2 6fps |
| | 1280 (H) x 1024 (V) pixels | MJPEG 30fps | YUY2 6fps |
| | 1280 (H) x 720 (V) pixels | MJPEG 60fps | YUY2 9fps |
| | 1024 (H) x 768 (V) pixels | MJPEG 30fps | YUY2 9fps |
| | 800 (H) x 600 (V) pixels | MJPEG 60fps | YUY2 21fps |
| | 640 (H) x 480 (V) pixels | MJPEG 120fps | YUY2 30fps |
| | 352(H) x 288 (V) pixels | MJPEG 120fps | YUY2 30fps |
| | 320 (H) x 240 (V) pixels | MJPEG 120fps | YUY2 30fps |
| Adjustable parameters | Brightness/Contrast/Color saturation /Definition/Gamma/WB | | |

| | |
|---|---|
| Night vision | optional, can choose IR board |
| View angle | 30-150 degree optional |
| Voltage | DC 5V |
| Current | 150mA |
| Work temperature | Degrees (-20~70) |
| Size | 32x32mm/38*38 |
| Support OS | WinXP/Vista/WIN7/WIN8<br>Linux with UVC<br>Mac-OS X 10.4.8 or later<br>Wince with UVC<br>Android 4.0 or above |

This specific camera comes equipped with both light filters and according to light sensitivity the filter changes automatically from IR to non-IR and vice versa. For the lens part, it was not clear how much zoom would be needed so a manual lens that zooms from 2.8-12mm was purchased. Finally, an IR filter was placed on top of the lens to cut the light of the projector at 850nm.


**Figure 28: Interface firewire camera with IR filter**

### 2.3.4 Illumination

- **LEDs**

Since it was decided to use the DI illumination setup, the LEDs needed were specific. Although, mentioned that the SMD IR LED arrays were the most fitting ones in theory, it was difficult not only to find them in Greece but also manufacture them. So, it was decided to use 3 small headlights bought from China, same as those mentioned in reacTIVision. These headlights consist of 4 LEDs each and are placed 4 magnifiers to focus the lighting on top of the LEDs.

After several experiments it was noticed that due to the magnifiers many hotspots appeared on the camera program and was therefore decided to remove them from each LED so the light will be diffused. In addition, using only 4 LED headlights was also a problem since a major part of the surface was not illuminated correctly. Fortunately, it was possible to find another headlight in Greece. The fourth headlight was smaller than the other three and consisted of 48 LEDs without a magnifier. After several experiments and hundreds of different mount spots, it was decided to mount the LEDs on each corner of the table, cycling the camera and the projector.

**Figure 29: Interface LEDs**

- **Reflective wallpaper**

In order to achieve a better light diffusion, a reflective wallpaper was placed on each wall inside the table. Such wallpapers can be found in greenhouses, and they are often used for growing seeds with technical lighting. These wallpapers are highly recommended when building such a machine.

In conclusion, after installing each component, the table was now illuminated correctly, and the surface was receiving enough light so the camera could read fiducials and fingers clearly and with less errors.

### 2.3.5 Projector

With a low budget setup like this it was not possible to buy a standard projector like those mentioned in Chapter 1. For this reason, it was decided to use one of those small projectors without a brand name, that are cheap and practical. The technical specifications of our projector are:

Input: 12V 1.5A

Dimensions: 117.5*83.6*43.5mm

Projection distance: 0.5-2.5m

Image size: 13-60 Inches

Audio: Stereo input

Lighting: LED

Resolution: 320*180

Brightness: 400 LUX

Contrast: 500:1

Input: USB, TF, HDMI, AV (3 in 1)

Although this projector is a type of short throw because the lower projection distance it provides is 0.5m, it was still needed to use a mirror to reduce the projection distance. After, experimenting with many different positions and mountings the projector was placed in the center of the table and place a small mirror in front of it. This made the projection light to cover the whole surface of the table and gave a clearer image. Finally, the camera was placed on top of the projector to reduce the deviation between them and have a more accurate interaction.

**Figure 30: Interface projector**


**Figure 31: Interface mirror**

## 2.4 Evaluation

At the initial stages of project design an evaluation phase was also programmed, which would have involved a pair-wise comparison between the original DX7 and the Synthtable by a number of participants. However, due to the pandemic this had to be replaced by a qualitative first-person evaluation, which was—nevertheless—based on input by an overly experienced DX7 user, who demonstrated the power of the original synthesizer and informed the implementation of the Synthtable.

Over a period of several months, a variety of possibilities were explored by interacting with the Synthtable and deducing tentative conclusions based on the experience we had with the original DX7 at the beginning of the project. As expected, the power of the Synthtable in comparison to the original DX7 seems to lie mostly in its intuitive interface. We present below a list with the advantages and disadvantages of the Synthtable:

**Advantages**

- Quick and easy access and selection of parameters without the complexity of hidden menus, as is the case in the original DX7; grasping a fiducial that is lying around the surface and throwing it onto the part of the surface that is visible by the camera seems to be an extremely effective alternative.

- Simultaneous adjustment of several parameters, which is impossible in the original design of the DX7, as menus need to be accessed in a sequential order.

- The power of graspable interaction: although the DX7 falls into the category of graspable interaction too, the size of objects fitting into the palm in the case of the Synthtable seems to offer an advantage in terms of interaction experience.

- Haptic component of multiple-finger interaction on the surface, to control the ADSR parameters rather than using knobs or buttons with binary representation.

- More effective graphical feedback projected on a large scale for guiding the adjustment of parameters, whereby parameter values are displayed just besides the manipulated object rather than separated by the associated controller (button or object for the DX7 and the Synthtable respectively).

-No special skills or musical knowledge required to use Synthtable, as it can be mastered only by interacting with it.

**Disadvantages**

- Limited portability due to the heavy and bulk frame construction.

- A new interface that a user needs to get used too.

- Occasional tracking loss due to lighting issues, mainly due to presence of hot spots or low lighting. However, these issues can be enhanced by using dimmable LED arrays in the table instead of non-dimmable LED headlights used in this project.

- Limited space to place fiducials, due to the low resolution of the projector used, which in turn required to zoom the picture on the table.

Overall, relatively to the low cost of implementation, Synthtable seems to be a successful solution that can potentially become a standalone interface for commercial use in the same level or even exceeding the reach of the traditional UI of the classic DX7 through appropriate enhancement.

# 3 Conclusions and Future Work

The aim of this thesis was to explore whether the use of a Tangible Tabletop Interface could possibly enhance the interaction paradigm of the original Yamaha DX7 synthesizer.

In the literature review the DX7 and the parameters of its algorithm were presented along with some general information about TTIs. A detailed presentation of the Reactable also took place, since we based *Synthtable* on Reactable's structure. Finally, a list of all the information on how to build a TTI was also presented.

In the practical part of the thesis, the *Synthtable* interface was introduced along with details on how to interact with it. Information about the software and hardware was also presented, followed by a small self-evaluation of the interface.

To conclude this thesis, we notice several advantages in the *Synthtable* design, such as the quick and easy access to parameters without using difficult menus. The graphical feedback towards the user and the multitouch control with fingers and fiducials are also some of the strongest points in *Synthtable's* design. Finally, the most notable advantage of the design is the ability to use it without any knowledge of music or programming.

While there are many advantages in *Synthtable's* design, it also poses some limitations that are worth mentioning.

The *Synthtable* uses an algorithm that emulates specific parameters of the Yamaha DX7 and not all of them. Attention was placed on its interaction possibilities and instead of producing an exact replica of the original DX7 audio engine, the Synthtable was developed to emulate only the basic DX7 audio functionality as a proof of concept. For time-saving purposes and due to insufficient budget, the audio engine was conditioned by the factors presented in subchapter 2.1.2. Furthermore, the low budget concept led to the use of materials that were not appropriate for the setup. This resulted in several problems with the lighting of the surface and the tracking of the fiducials.

In terms of future work, it is recommended to recreate all the 32 voices of the traditional algorithm of the DX7 system, inside the *Synthtable*. A more appropriate frame would give a higher flexibility in transporting the *Synthtable*, making it easier to be assembled and disassembled in museums, live concerts etc. The current lighting could be replaced with four or more dimmable LED arrays for better control and even spread of the light inside the table. The projector could also be replaced with a real short-throw type that has a better image quality in close range. In that case, the mirror placed inside the table could also be removed. Another important parameter is the tracing paper. It would be more appropriate to use a thin layer of a sandblasted Plexiglas as it will not be able to tear or crumble. A near future improvement could be to make the *Synthtable* a plug and play musical instrument by placing a latte – panda pc inside the frame leaving only the power cable outside of the frame. We also recognize that the instrument needs an additional interface to control the global parameters of the instrument instead of relying on an external MIDI controller. Implementing such functionality will eliminate the need for external MIDI controller. Finally, another important near future recommendation is the evaluation of the *Synthtable* by other users. The live evaluation of the *Synthtable* by simple users and musicians will enhance this research; such interaction will lead to a better understanding of the instrument and its possibilities.

In conclusion, Tangible Tabletop Interfaces present a new way of interaction with traditional UIs. This thesis contributes only to a small spectrum of the numerous possibilities the augmentation of an old traditional UI can offer. According to the results of this thesis, TTIs can successfully be used to establish an enhanced interaction between a user and the Yamaha DX7.

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