# A New Mix of Forgotten Technology: Sound Generation, Sequencing and Performance Using an Optical Turntable

Nikita Pashenkov
Murkin Laboratory
2-16-17 Jingumae, Arakawa Bldg. 303
Shibuya-ku, Tokyo, Japan 150-0001
nik@ratstar.com

## ABSTRACT

This report presents a novel interface for musical performance which utilizes a record-player turntable augmented with a computation engine and a high-density optical sensing array. The turntable functions as a standalone step sequencer for MIDI events transmitted to a computer or another device and it is programmed in real-time using visual disks. The program instructions are represented on printed paper disks directly as characters of English alphabet that could be read by human as effectively as they are picked up by the machine's optical cartridge. The result is a tangible interface that allows the user to manipulate pre-arranged musical material by hand, by adding together instrumental tracks to form a dynamic mix. A functional implementation of this interface is discussed in view of historical background and other examples of electronic instruments for music creation and performance incorporating optical turntable as a central element.

## Keywords

Interaction, visualization, tangible interface, controllers, optical turntable, performance.

## 1. INTRODUCTION

The idea of a musical instrument based on the coupling of optical technology with a turntable is not new. In fact, some of the earliest electronic instruments used a rotating turntable platter in conjunction with a photocell, since both technologies were among the earliest tools of playback and electronic instrumentation. Having gone through several decades of evolution, however, the development of such instruments had all but ceased in 1970's.

The next section outlines a brief lineage of optical turntable instruments. This research is accompanied by a functional prototype of a new musical interface that seeks to establish a continuity with the historical tradition, while taking inspiration from a contemporary breed of music created and/or played with a disk-jockey turntable. The focus of the project is two-fold. First, to revive an extant metaphor of an optical turntable as a musical instrument. Second, to suggest that this kind of instrument can form a new link between two types of contemporary music and their audiences, which can be categorized roughly as turntable 'mix' music and popular electronic music.

One of the earliest intersections of these genres was the famous remix of the song *Trans-Europe Express* by German electropop pioneers Kraftwerk, featured on the 1982 single *Planet Rock* by DJ Afrika Bambaataa. [1] Although there is a world of difference between the roots of futuristic music performance in Düsseldorf and an open-air party held in the Bronx, the two have found a common thread that gave rise to a multitude of popular and dance music styles of today, such as hip-hop, techno, electro, house, etc.

This commonality is best seen in relation to a pre-cursor of contemporary popular music genres, rock'n'roll. In contrast to the emotional image of a rock performer in the middle of a guitar solo, the DJ and electronic musician appear as cool and often expressionless manipulators of sonic material that seemingly generates itself. The two genres also share a similarity in their rhythmic approach to musical composition. The electronic musician programs his or her drum machines, synthesizers, and sequencers. DJs too refer to the act of arranging tracks during performance as 'programming.' The primary function of a disk jockey is that of a dynamic sequencer, manipulating and combining tracks from various records together to form a musical collage known as the *remix*.

**Figure 1: *Diskotron*, a functional hardware prototype of a new optical turntable instrument**

Nevertheless, there is big divide between the two types of music, owing to the difference in the capability of respective performance tools. The turntable is understood as a playback device for manipulation of recorded material, limited by comparison to an electronic instrument. On the other hand, it is often the case that in live performance, programmable synths and software arrangements leave the electronic musician with little room for interaction beyond the equivalent of turning knobs, whether real or virtual. From this perspective, the turntable offers a superior interaction modality and one that is engaging for the audience to watch.

The aim of the Diskotron project is to chip away at the difference between two genres of contemporary popular music by putting real programming power literally into the hands of a disk-jockey or, looking at it the other way, to provide an electronic musician with a tool for manipulating the performance material interactively in an engaging manner.

## 2. BACKGROUND

What we might call optical turntable instruments had their genesis in the early part of last century. For example, the first wavetable synthesizers used glass or film disks, where a looped sound was encoded as an optical track, circling the disk in a series of concentric rings. The simplest instrument based on this technique was *Cellulophone* ("Cellule PhotoÈlectrique") invented by the French engineer Pierre Toulon in 1927. Cellulophone used rotating disks with a ring of up to 54 equidistant slits cut into them. A light source positioned above the disk flashed through the slits onto a photoelectric cell below, connected to a vacuum tube oscillator. An inverse proportion of the number of slits on each disk thus determined the frequency of the sound produced by it. [2]

A slightly more sophisticated instrument used a picture of the actual waveform to generate sound. *Welte Light-Tone Organ* (1936), designed by E. Welte in Germany, utilized several optically controlled tone generators. A glass disk was printed with 18 different waveforms rotated over a series of photoelectric cells, filtering the light beam that controlled the sound timbre and pitch. [3] Ivan Eremeef and Leopold Stokowski used a comparable strategy in Syntronic Organ (1936), an instrument that was able to produce "one-hour of continuous variation" created by an optically generated tone using film disks. Similar instruments include *Radio Organ of a Trillion Tones* (1931) and the *Polytone Organ* (1934) by A. Lesti and Fredrick Sammis, USA. [4]

A precursor to the instruments described above was truly ahead of its time. *Piano Optophonique* created in 1916 by the Russian Futurist painter Vladimir Baranoff-Rossine generated sounds and projected revolving patterns onto a wall or ceiling by directing a bright light through a series revolving painted glass disks, filters, mirrors and lenses. Rossine's colorful disks were made audible as a result of the variations in opacity of the paint, which filtered a light source shining through them. [5]

The most complex instrument based around photocells coupled to the vacuum tube oscillators was *RCA Synthesizer* (1952), invented by the electronic engineers Harry Olsen and Hebert Belar. While this instrument used visual paper graphs rather than circular disks for input, the turntable also provided an essential functionality: the audio produced by the synthesizer was recorded by an internal lacquer disk cutter. By re-using and mixing the disk recordings, a total of 216 sound tracks could be assembled together. [6]

In addition to wavetable synthesis, the optical turntable also provided a basis for some early sample-playback instruments. For example, *Hardy-Goldwaithe Organ* (1930) was a keyboard instrument that utilized optical disks with 71 sampled notes encoded on them. Turntable-based optical sample players even had a brief commercial existence in the early 70's in the guise of the aptly named optical-organ *Optigan*. [7] This low-cost keyboard instrument played sounds generated from graphic representations of waveforms contained on interchangeable 12" celluloid discs, which were sold at department stores like Sears. A 'professional' version of Optigan was later marketed under the name *Orchestron*. Among the musicians who utilized it were the progressive rock group Yes, and Kraftwerk.

There is one example of a contemporary instrument that explores the unique potential of the optical turntable. *Photosonic Instrument,* conceived and developed by the French musician Jacques Dudon since 1984, utilizes optical disks that filter a light falling onto a photocell just like its predecessors. The inventor's original contribution was to add an optical grating filter as an additional

**Figure 2: Examples of disks used by Welte Light-Tone (left) and Piano Optophonique (right)**

stage of light filtering. Using a graphical representation of complex musical shapes, combined with manipulation of the light and filter by hand, Dudon is able to achieve advanced forms of articulation and timbre shaping, switch between samples, and to blend or cross fade between various sounds. [8]

## 3. IMPLEMENTATION

The history of precedents for this project, as detailed in the previous section, has one feature in common: optical turntable instruments that have existed are all based on analog technology of past decades. The idea behind Diskotron is to couple the visual disk metaphor to a digital processing core. This provides the initial imperative to focus the project on qualities that differentiate it from its analog cousins. Therefore, the starting aim was to build a digital sequencing instrument that could be used as an interface for real-time structuring and manipulation of musical events.

### 3.1 Hardware

The hardware platform for this project is built around a type of record player known as a linear-tracking turntable. This type of turntable was chosen as it allows for precise positioning of the cartridge over the surface of the disk as well as a means of its actuation (the existing turntable motor and gear setup are utilized, but the connections are rewired to a locally-controlled motor driver chip). A rectangular plate that folds over the back portion of the rotating platter provides a chassis on which the turntable electronics are positioned. The 'motherboard' circuit is composed of three processors, each running a set of dedicated tasks. The block diagram in Figure 3 outlines the functional breakdown of augmented turntable's hardware.

The data flow begins at the optical cartridge circuit. The cartridge features a high-density optical array (TSL3301 by Texas Advanced Optoelectronic Solutions), a focus lens array, target illumination LEDs, and a few passive electronics components. The TSL3301 is a small-factor chip that contains a 300-dpi, 102 pixel linear optical sensor array with integrated 8-bit analog-to-digital converters. [9] The optical sensor is controlled by a processor that accumulates the pixel data and passes it on to the central processor. For this prototype, an SX-18 micro from Ubicom was utilized, running at 50Mhz to enable speedy integration and data collection. [10]

At the next stage, the pixel data is fed to the central processor, currently implemented using an RCM2300 module by Rabbit Semiconductor. [11] This unit is clocked at 20Mhz and provides ample space in RAM and flash memory (256K each) to allow a small-scale image processing program to be implemented on the chip. RCM2300 thus has sufficient processing power and memory to host a program that accumulates image data into a running buffer, resolves it into discrete pixel values, and performs simple character recognition.

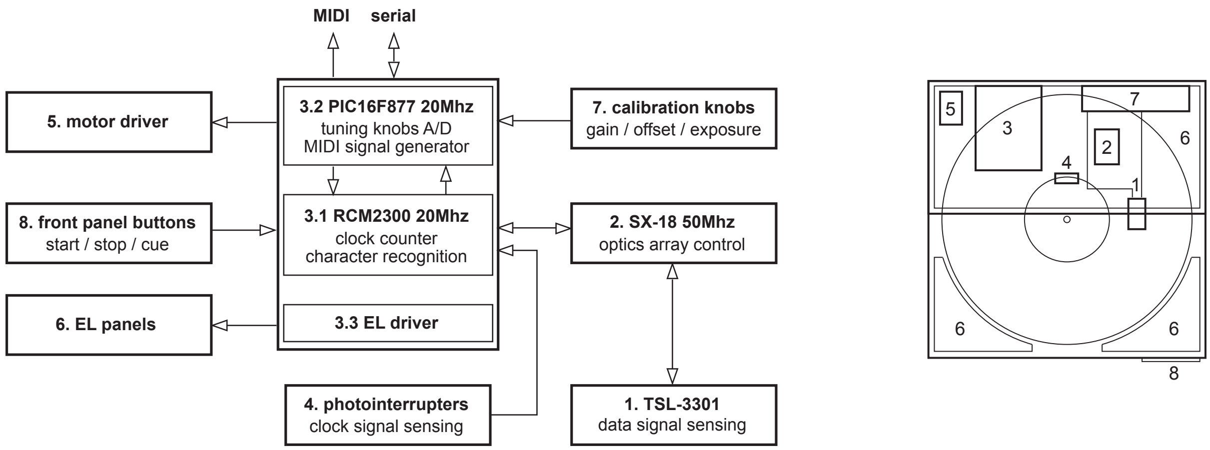


**Figure 3: Functional block diagram (left) and corresponding layout (right) of Diskotron hardware.**

In order to resolve pixel values correctly, a special optical 'clock' track is provided at the edge of the innermost circle on each paper disk. The clock track consists of equidistant markings that are picked up by a small module with two reflective photo-interrupter sensors mounted on it. The module's output is connected to the central processor, which is able to calculate the direction and speed of the turning disk using simple two-sensor geometry.

Once the central processor extracts several data characters representing a single command, it writes their 8-bit value to the PIC16F877 processor, which represents the last stage in digital data flow on board the turntable. This processor's primary function is to convert the received values into an out-going MIDI stream. In addition, an integrated 8-channel A/D converter on the PIC services an external module that contains several potentiometers. These tuning knobs can be used to adjust several built-in parameters of the optical sensor array. As one might expect from an optical instrument, settings for exposure, gain, and offset of the received signal need to be calibrated at the beginning of a performance.

## 3.2 Optical Disks

For the first-generation Diskotron prototype described here, an 8-step sequencer has been implemented at the microcontroller level. The sequencing instructions are inscribed as visual markings on the surface of a paper disk and take the form of digital codes that are rendered as characters of English alphabet. For example, a three-letter command 'MV2' signals the microcontroller to move the cartridge to the second track on the disk, command 'RE3' causes the sequencer to repeat a given track three times, and command like 'C4' causes the turntable to produce a MIDI equivalent of this note. In short, the optical turntable paper disks are sequencing programs and the programs are composed of word-statements printed on the surface of the disk. Playing a disk on the turntable is therefore equivalent to programming the internal controller electronics to produce a sequencing arrangement in real-time.

## 3.3 Software

In order to facilitate the creation of optical disks, an interactive software application has been written in C++/OpenGL. The program draws a representation of a disk on the computer screen and enables the user to navigate between separate tracks and step sequence slots within each track using a keyboard or a mouse. Command-codes are then inserted in each slot by typing them. Once the disk arrangement is completed, a PostScript file can be generated, ready to be sent to a compatible printer.

# 4. ANALYSIS

This section is divided in two portions. First, a discussion of this project looks at it in relation to historical precedents as well as contemporary attempts to utilize and/or augment the functionality of a turntable. Second, an analysis of technical implementation issues pertaining to project hardware and software is given.

## 4.1 Precedents and competition

Due to the rise in popularity of turntable mix music, the recent years saw a number of new products and developments aiming to provide a link between a turntable and a computer. Most popular are software solutions (*Traktor DJ Studio* by Native Instruments [12] is perhaps the most feature-rich application) that emulate the disk jockey setup and provide the means to manipulate digital tracks using a keyboard, mouse, or external MIDI controllers. A more comprehensive approach is taken by Stanton, Inc. with *Final Scratch.* This product consists of a software component, specially encoded vinyl records, and a hardware box that enables the user to utilize an actual turntable as an interface to a computer. [13] However, these state-of-the-art commercial offerings do not explore the potential of their product far beyond emulation - the turntable still remains primarily a playback device.

A paper submitted to this conference last year describes a prototype turntable-to-computer interface which suggests that there is a new generation of ideas in the air. Based around the concept of a software framework visualized as a projection on top of the turntable platter, the project hints at the possibility of structuring a highly interactive experience for both the disk jockey and the audience. [14] Another recent experimental project describes a set of approaches to utilize haptic technologies in the construction of a DJ interface. The authors implemented a tactile feedback mechanism which allows the user to 'feel' various qualities of sonic material and enabled new possibilities for sound generation, such as parametrized 'scratching' controlled by software. [15] It must be noted, however, that such innovative projects are nevertheless limited in aim to augmenting the sound-manipulation capability of a turntable rather than taking it in a wholly new direction.

In comparison to the recent attempts at utilizing the turntable as a musical interface, analogues to electronic instruments given in the background section are more relevant to this project. We might say that Diskotron in its current state is a sequencing instrument comparable in function to that of RCA synthesizer's lacquer disk cutter, offering a possibility to play separate tracks of music, manipulate their tempo and to mix them together. The obvious advantage is that the printed paper disks make this process insignificant in cost and near-instantly reproducible.

The main difference between this project and its historical predecessors is that the disks contain digital information spelling out program instructions, rather than sound waveforms. At this stage, a minimum of instructions has been provided enabling the turntable to send MIDI note and continuous controller value messages, and to move the cartridge between different tracks of data. However, this functionality represents only a fraction of possibilities for the current hardware configuration.

Interfacing the optical turntable to a computer presents another range of possibilities. For the purposes of composition, the feedback loop that occurs between the turntable and the software that receives its commands hints at a unique possibility. The software application for creating PostScript disks already acts as a channel for receiving data from the turntable. Plotting the MIDI messages against the speed and direction variables sent over serially, a virtual equivalent of the playing disk is constructed. Any manipulation of the actual disk translates into corresponding changes in the virtual representation. This disk can then be captured and printed at any point, completing the composition feedback cycle.

Finally, the digital codes are but the most sensible instructions designed to be interpreted by the turntable microcontroller. A range of analog visual representation on the surface of the disk remains to be explored. It is not an exaggeration to assert that any visual material can be fodder for experimentation on the optical turntable. A study of Jacques Dudon's photosonic instrument suggests that 900 disks so far devised for it constitute only a small part of the musical material accessible to the optical disk technology. [8] By offering the potential to mix between digital and analog representation (even on the same disk), the Diskotron project clearly has more than enough room to grow.

## 4.2 Technical features and limitations

The optical turntable prototype that is described here should be considered an initial attempt to bring the desired functionality together using a few patches of computational hardware loosely tied together. In the tests carried out so far, the microcontroller engine proved to be very robust, arguably superior to any solution incorporating the overhead of a PC computer and an operating system. The embedded hardware is speedy enough to run a full cycle of computation (read 100 pixels and parse them, extracting a single cross-section of data) at a rate of over 1000 per revolution. Depending on the position on the disk, this provides a sub-millimeter resolution for each interpreted pixel. The computational core could benefit from a performance boost with a faster processor, however, enabling more sequencing steps and higher density codes to be interpreted.

One way to improve the performance of the system substantially with the existing hardware configuration is to forgo the use of English alphabet characters. A test has been carried out using digital-coded values with Hamming error detection and correction. The effective bandwidth of the system was thus nearly quadrupled. However, this scheme detracts from the impressive feature of the preferred albeit less-efficient system of encoding. By using actual characters as input to the optical turntable, an ever-present layer of abstraction is taken away and the program code becomes instantly readable by a human.

# CONCLUSION

This document outlined a rich domain of inquiry. There exists a lineage of electronic instruments that utilized the idea of an optical turntable for the purpose of sound and even image generation. In recent decades, a curious phenomenon of subverting the technological intention of the record-player turntable for the purpose of musical expression has evolved. A few attempts to utilize this new type of interaction metaphor have been analyzed, which generally fall short of addressing the potential of a turntable as a full-featured instrument. The Diskotron project seeks to find new ground between the historical legacy and possibilities afforded by digital technology. A functional interface has been described, the initial application of which enables dynamic real-time sequencing of musical events during performance. A synthesis engine is currently under development, which may elevate the status of Diskotron to that of a true heir to optical turntable synths that preceded it.

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