cutting record
- a record without (or with) prior acoustic information

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ABSTRACT
In this paper, we present a method to produce analog records with vector graphics software and two different types of cutting machines: *laser cutter*, and *paper cutter*. The method enables us to engrave a variety of wave forms on a surface of diverse materials such as paper, wood, acrylic, and leather without or with prior acoustic information. The results could be played as analog records with standard record players. We present the method with its technical specification and explain our initial findings through practices. The work examines the role of musical reproduction in the age of personal fabrication.

Keywords
Analog Record, Personal Fabrication, Media Archaeology

1. INTRODUCTION

"I have suggested to change the gramophone from a reproductive instrument to a productive one, so that on a record without prior acoustic information, the acoustic information, the acoustic phenomenon itself originates by engraving the necessary Ritchriftreihen (etched grooves)."

László Moholy-Nagy, 1923 [13]

In 1923, László Moholy-Nagy, master at the bauhaus, proposed to produce a record without prior acoustic information. It is not clear whether he succeeded or not to achieve the anticipated results, however, the coming practitioners followed his notion with a knife to form different rhythmic patterns on the surface of record (Brinkmann, Thomas, Klick, 2000), or with a second hole to rotate the record off center to induce variations in pitch and speed (Non, Pegan Muzac, 1978) [15]. In this paper, we propose an alternative method, which legitimately follows the notion with a help of vector graphics software and current cutting machines.

Analog records have its origin in 1858, the invention of Phonoautograph by Leon Scott. At the moment the device only could transform the vibration of sound into graphical forms, however, after over a century, researchers renewed the history of earliest audio recording by decoding the sound from its graphical forms [4]. In 1878, Frank Lambert made the talking clock, the first machine, which could play back the inscribed sound into lead with its own mechanism. After few months, Thomas Edison made the Phonograph, which record and reproduce (mainly) voices with a vertically vibrated stylus and a tin foil on a cylinder. In 1887, Emile Berliner proposed the Gramophone to record sounds on a disc. The Gramophone used a flat disk rotated on a horizontal plate as a recording surface. In it's recording, a vibration of air according to time (i.e. sound) is converted into a horizontal vibration of stylus to etch a groove into the rotated surface. In play back, the procedure works in a reverse order. The stylus moves along the groove and the vibration is mechanically / electronically amplified to produce a monophonic sound (Figure 1). The mechanism also allowed multiple duplications with casting technique.

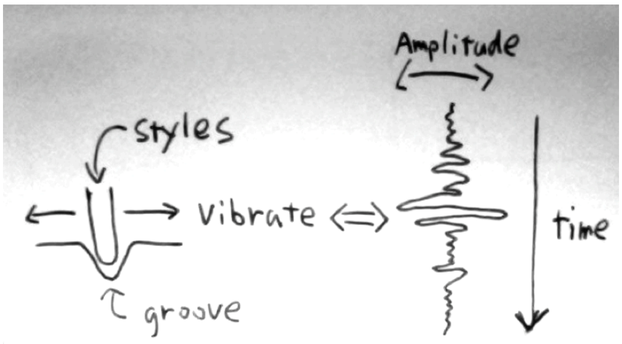

Figure 1. How a record works

After the Gramophone, the basic mechanism of record continued for a century with several inventions and experiments. For example, the change of diameters and rotational speeds, the appearance of 45/45 stereophonic recording in 1950's [7], and a laser turntable in 1980's [9]. Diverse materials were tested for the disc include not only standard shellac and vinyl but also other experimental stuff such as rice cake in 1920's [8], chocolate [16], or ice [18]. In the late 1960's to 1970's, Dubplate was come from a reggae music scene. It uses an acetate disc, a recordable fragile disc originally invented for testing purpose with cutting machine. They used the disc to produce an original version (i.e. mixing) for their sound system [17]. The culture of making a unique record has been continued since then such as a building of hand made cutting machine on a CD [1], 3D Printed Record [6], or cutting four grooves which cross on each side [11].

2. cutting record

In our method, we follow the invention of Berliner's gramophone. Instead of using a vibration and a stylus, we employ a computational vector line, and a laser beam or a cutter blade of cutting machine, to engrave a wave form as a groove on a flat surface. The resulted groove could be played as a monophonic record in a same manner as its ancestor. In following sections, we describe the two cutting machines and two distinct ways of producing analog records without (*record-without*), or with (*record-with*) prior acoustic information.

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2.1 cutting machines

To engrave a groove on a surface of material as a playable record, we have used two different types of cutting machines: *Laser cutter* (Universal VLS 2.30) and *Paper cutter* (Silhouette Cameo). Each cutting machine provides a driver software to work with several graphic applications in a similar way to standard printer.

Laser cutter is a device to engrave or cut images on a material with a laser beam. To compare with it to standard inkjet or laser printers, it could produce the image without physical contact instead of printing the image with substantial ink or toner. Because of its principle to burn away a surface of material, it is difficult to treat some materials such as vinyl, which produce poisonous gas or metals with reflective surface. Beside that, it could be used with diverse materials such as paper, wood, acrylic, and leather. Normally, a laser cutter provides two modes: raster, and vector. In raster, the laser beam horizontally scans (i.e. burn) the surface based on a bitmap or painted data. In vector, the laser beam outlines on the surface to make a continuous line for engrave and cut based on a vector data. In our case, we mainly used the vector to engrave the wave forms.

Paper cutter uses a thin cutter blade in place of a laser beam to engrave or cut an image. It works in a similar way to laser cutter. Based on its structure to rotate the blade on the surface, it only could treat vector data with thin materials such as paper, adhesive vinyl, or film. Normally, the cost of a paper cutter is about one hundredth of a laser cutter (e.g. $200 vs. $20,000).

2.2 record-without

This is a record without prior acoustic information (*record-without*). As Moholy-Nagy suggested, it directly originates acoustic phenomenon from a graphical form. In this type, we use a standard vector graphics software (i.e. Adobe Illustrator) to draw a wave form as a computational vector line. Here is a case of making a locked groove (i.e. a concentric circle). With the groove, we could approximately have a range of time from 1.8 seconds in 33RPM (60 sec / 33.3) to 1.3 seconds in 45 RPM (60 sec / 45).

0) Draw a circle.
1) Divide it into a collection of arcs with the scissors tool.
2) Apply the Smooth zigzag effect (Filters > Distort > Zig Zag) for each arc (Figure 2).

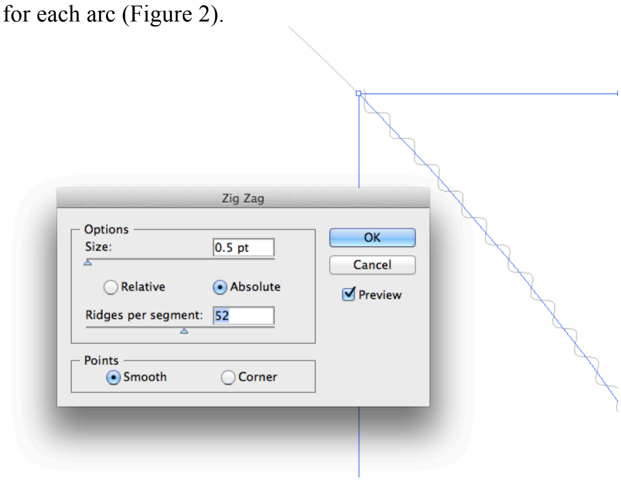

Figure 2. Apply zigzag effect to an arc

The size of zigzag defines the amplitude (i.e. volume) of the wave form. Because of the range of time, when we equally divide the circle into X arcs and apply Z numbers of ridge for each arc, we could have Y vibrations in second (i.e. frequency) with following function.

*Frequency: Y (Hz) =Arcs: X * Ridges: Z / 1.8 (or 1.3)*

If we apply the zigzag effect at regular intervals, we could have a beat. We also could transform the wave form (e.g. draw an envelope) with diverse effects of Illustrator. After applying the effects, the arcs need to be connected as a groove.

3) Draw a periphery circle to satisfy a desired size of record (7inch=177.8mm, 10inch=254mm, or 12inch=304.8mm).
4) Make a hole in the center (7.24mm in diameter).
5) Adjust the diameter of the zigzag effected circle to fit it into a form of record.
6) Add other information (e.g. title, name) within the circle.
<optional for laser cutter>
7) Differentiate the peripheral circle and the hole for cut, and the effected circle and other information for engrave with different color.
8) Cut the data through cutting machines.

We also could extend the method into a standard spiral groove. In that case, by using the spiral tool in Illustrator, we could attain longer range of time.

2.3 record-with

This is a record with prior acoustic information (*record-with*). In this type, we convert a digital audio data into a vector graphic form with software. Here is a case of making a locked groove with SoX (Sound eXchange), gnuplot, and Adobe Illustrator.

0) Prepare a digital audio data with the range of time (1.8 seconds in 33RPM, 1.3 seconds in 45RPM).
1) Convert the audio data with standard uncompressed formats (e.g. .aiff or .wav) to .dat with SoX. SoX is a command line utility to convert various formats of computer audio files in to other formats (http://sox.sourceforge.net/). With the conversion, we could treat each sample of the audio data as text lining up in time series.
2) Draw a continuous vector line (i.e. wave form) with the text as SVG (Scalable Vector Graphics) by using a graphing utility gnuplot (http://www.gnuplot.info/).
3) Import the SVG and make an art brush of the wave form with Illustrator.
4) Draw a circle.
5) Apply the art brush to the circle (Figure 3).

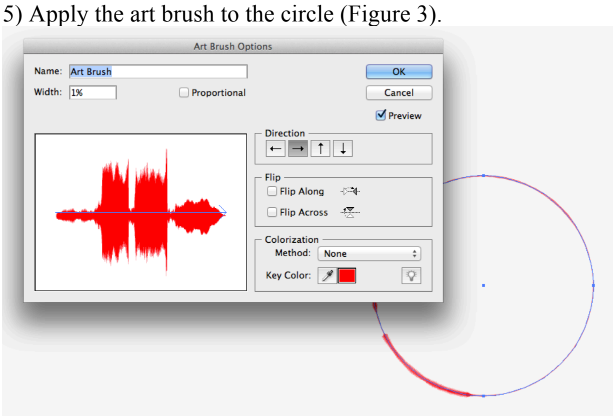

Figure 3. Apply an art brush of a wave form to a circle

The width of the circle defines the amplitude (i.e. volume) of the wave form in the same way as record-without.

6) Draw a periphery circle, make a hole, add other information, and so forth.

To extend the method into a spiral groove, we made a custom application with processing (see appendix). The application generates a spiral groove with peripheral circle and a center hole in a form of SVG file based on given audio data (Figure 4). The application provides parameters of diameter, sampling rate, rpm, amplitude, line space, and margin for adjustment. The resulted SVG file is imported in Illustrator for cutting.

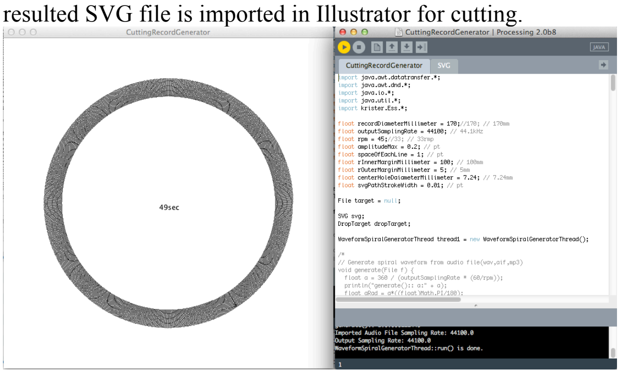

Figure 4. Generates a spiral groove from audio data

3. EXTENDED TRIALS

In this section, we explain some use cases, which we tried in our initial practice.

Puzzled record

This is a reconfigurable record without prior acoustic information made with a laser cutter. It consists of a collection of arcs, and a circumscribed and an inscribed circle. Each arc was produced from a locked groove by splitting the circle with a laser beam. The ends of a groove on each arc were centered to connect them each other. The circumscribed and the inscribed circles work as boundaries to avoid scatter by centrifugal force. With this record, people could produce different beats by changing the order of the arcs. The record could have a multiple appearance by combining different materials with a same thickness (Figure 5).

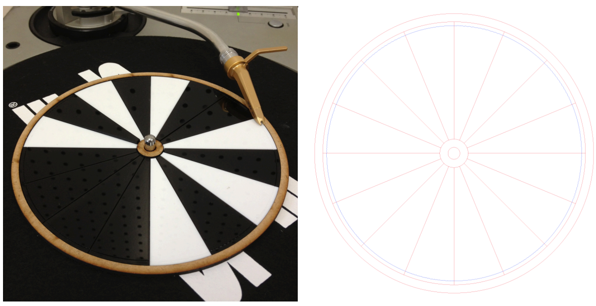

Figure 5. Puzzled record made with acrylic and wood

DIY record workshop

We organized a workshop at IAMAS "One Step Back, Two Steps Forward" exhibition on 2012/12/22 at Shibaura House (https://www.facebook.com/OneStepBackTwoStepsForward). In the workshop, we have 10 participants with diverse backgrounds include DJ, web designer, music label owner, and students. Through the 3 hours workshop, each participant made her/his own record (*record-without*) with preferred material by using Adobe Illustrator, a laser cutter, and a paper cutter (Figure 6). We provided a step-by-step guide [10], and a software to calculate the number of ridges to produce desired frequency (http://db.tt/1tUhUUGr). After the workshop, some participants performed the resulted records as DJ in back to back style. The results was released as a compilation of data at digital design sharing site (see appendix).

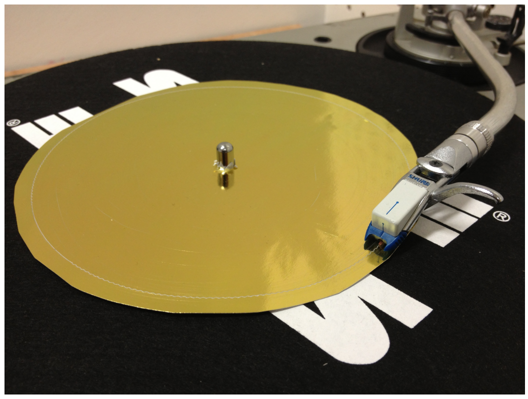

Figure 6. A metallic paper record made by a participant

4. DISCUSSION

Thorough our practice, we have observed following issues in our method.

Sampling frequency

For *record-with,* we need to adjust the sampling frequency of source audio data in relation with the resolution of the cutting machines. The value also relates to the maximum number of ridges in *record-without*. The sampling frequency determines the number of samples per second. According to Ghassaei's work [6], we could calculate the sampling frequency with a following formula.

*Sampling frequency = (Resolution per inch) * (Inches per revolution) * (Revolution per second)*

Our laser cutter (Universal VLS 2.30) provides 1000dpi (0.0254mm intervals) and our paper cutter (Silhouette Cameo) provides 508dpi (0.05mm intervals) as their resolution. RIAA standards define a radius of a groove in standard 12inch (30cm) record from 2.25 to 5.75 inch (57.15 to 146.05 mm) [7]. From the values, we could calculate the range of the inches per revolution (*2*pi*radius*) from 14 to 36 inch (35.89 to 91.44mm). The revolution per second is 0.55 in 33RPM (33.3/60) and 0.75 in 45RPM (45/60). With the values, we could have following sampling frequencies to prepare the audio data.

Table 1. Obtainable sampling frequencies of cutting record

Cutting Machine	RPM	circum-ference	Sampling Frequency (Hz)
Laser cutter	33	outer	1000*36*0.55 = 19,799
		inner	1000*14*0.55 = 7,700
	45	outer	1000*36*0.75 = 27,000
		inner	1000*14*0.75 = 10,500
Paper cutter	33	outer	508*36*0.55 = 10,058
		inner	508*14*0.55 = 3,911
	45	outer	508*36*0.75 = 13,716
		inner	508*14*0.75 = 5,334

Theoretically, the half of the sampling frequency defines the maximum frequency of the sampled signal. To compare the results with the frequency response of a standard record (e.g. 20 kHz in LP), we could have approximately one-tenth (Paper cutter at 33RPM on inner circle) to two-thirds (Laser cutter at 45RPM on outer circle).

Limitation of anchor points

We have faced limitations of anchor points in both vector graphics software and cutting machines. With *record-without*, we have used the zigzag effect of Illustrator to have vibrations (i.e. frequency) with the resulted groove. However, the zigzag effect has the upper limit (100) on the number of ridges (i.e. anchor points). Therefore, if we would like to have higher frequency, we need to repeatedly apply the effect to divided arcs (e.g. 1000Hz in 33rpm needs 18 arcs with 100 ridges on a revolution). Illustrator also has a limitation in the number of anchor points of a single path (i.e. continuous line) around 32,000. For *record-without*, it is not a matter because we've already divided the path into arcs as we described above. However, for *record-with*, it restricts the range of time in relation with the sampling frequency (e.g. 0.7sec in 44.1KHz). Therefore, in our custom application, we divide a groove into multiple paths with overlap to achieve longer range of time. The driver software of cutting machines also show limitations with graphic applications. With our trials, the driver of paper cutter could not treat data with anchor points over around 100,000. The laser cutter also has a similar problem with Illustrator. Therefore, we avoid the problem by using a direct import function of the laser cutter. For the paper cutter, we're planning to directly control the machine with custom application.

Melt and hook

Melt by a laser beam, and hook with a cutter blade prevent us to reach desired results in accuracy of resulted sounds. With laser cutter, we burn away a surface of material with a laser beam. The burning causes a tiny melt or scorch at the edge of the resulted groove. With paper cutter, the cutter blade physically contact with a material. The contact causes several hooks with materials when it rapidly changes its movement. In each case, the smallest changes in the groove will disappear and result a loss of treble in sound. With laser cutter, we could achieve higher accuracy by using high-density focusing lens with smaller spot size (0.025mm). The lens also enables us to decrease gaps between cut parts (e.g. arcs in puzzled record). With paper cutter, we're planning to use papers made with shorter/thinner fibers to prevent hooks.

5. CONCLUSION

We presented a method to produce analog records on diverce materials with vector graphics software and cutting machines. The method combines the current computational environments and the mature audio technologies to provide a way to think the new and the old in parallel lines [14]. The sound quality of the resulted records is relatively lower to compare with it to standard analog records. It contains a sound of stepping motor (see appendix), and takes long time for production (e.g. 9 hours for 5 min). However, especially, in the case of *record-without*, the record is no longer a work of mechanical reproduction [2]. Instead the record is a craft of personal fabrication [5]. In the last century, “We would become practiced in selecting what we wanted to hear, but not practiced in producing stuff for others to hear” [12]. As the cheap bass/drum machine (i.e. TB-303/TR-808) caused the birth of Techno music [3], we would like to revive people do not just “listen” music but also “cut” their own music with our method.

6. ACKNOWLEDGMENTS

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8. Appendix

The custom application for *record-with* could be downloaded at https://github.com/mitsuhito/CuttingRecordGenerator.

A compilation of DIY record workshop could be downloaded at http://www.thingiverse.com/thing:51923.

A collection of the production process could be watched at https://vimeo.com/channels/300753.