Two Turntables and a Mobile Phone

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ABSTRACT

A novel method of digital scratching is presented as an alternative to currently available digital hardware interfaces and time-coded vinyl (TCV). Similar to TCV, the proposed method leverages existing analog turntables as a physical interface to manipulate the playback of digital audio. To do so, however, an accelerometer/gyroscope–equipped smart phone is firmly attached to a modified record, placed on a turntable, and used to sense a performers movement, resulting in a wireless sensing-based scratching method. The accelerometer and gyroscope data is wirelessly transmitted to a computer to manipulate the digital audio playback in real-time. The method provides the benefit of digital audio and storage, requires minimal additional hardware, accommodates familiar proprioceptive feedback, and allows a single interface to control both digital and analog audio. In addition, the proposed method provides numerous additional benefits including real-time graphical display, multi-touch interaction, and untethered performance (e.g "air-scratching"). Such a method turns a vinyl record into an interactive surface and enhances traditional scratching performance by affording new and creative musical interactions. Informal testing show this approach to be viable, responsive, and robust.

Keywords

Digital scratching, mobile music, digital DJ, smartphone, turntable, turntablism, record player, accelerometer, gyroscope, vinyl emulation software

1. INTRODUCTION

The performance practice of DJing has experienced astonishing growth over the past three decades. Scratching, beat-matching, beat juggling, mixing, and similar techniques can be heard on the radio, in night clubs, and experimental music contexts around the world. All such performance styles can be traced back to the unique physical interaction and expressive nature of a simple mechanical device–the analog turntable. The simple physical control and inherent proprioceptive feedback affords the possibility of incredible virtuosity and skill without hindering a beginner's zeal.

With the advent of digital audio, however, great attention has been focused on digital implementations of the turntable so as to leverage the many benefits of digital storage and playback. Such implementations typically fall within two categories: methods leveraging existing analog turntables with certain modification and methods requiring alternative hardware mimicking the turntable's control. Examples of the prior include time-coded vinyl (TCV), while examples of the latter include CDJs or similar interfaces [2, 1, 4, 3]. TCV uses a vinyl record encoded with time-code to detect needle position, where as alternative hardware uses various alternate sensing mechanisms. Both approaches have distinct advantages and disadvantages, largely dependent on personal preference and performance style.

In many traditional DJ settings, time-coded vinyl methods have proven overwhelmingly popular. TCV methods allow a single interface to control both analog and digital audio and maintain the familiar and nimble scratching control of a traditional analog turntable. Disadvantages include wear and tear on the vinyl record, limited duration of the TCV records, possible jumps in needle position during a performance, and physical interference of the turntable tone arm.

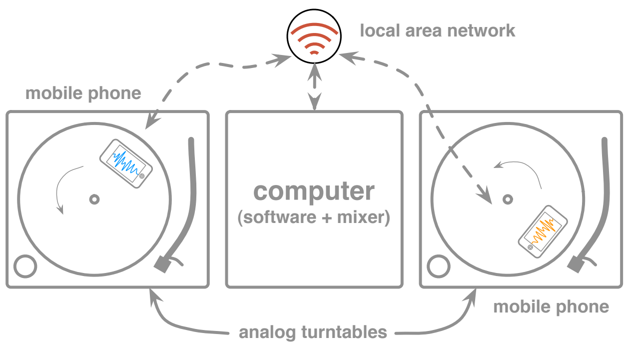

Figure 1: Proposed DJ Setup. The system uses turntables and sensor-equipped mobile phones, networked with a host computer.

In this work, a novel method of digital scratching is presented as a viable alternative to currently available digital hardware interfaces and TCV. The proposed method leverages existing analog turntables as a physical interface to manipulate the playback of digital audio, but does not require a time-coded record or any physical connection to a digital audio playback device. An accelerometer/gyroscope–equipped smart phone atop a modified record is used to wirelessly transmit gesture data to a computer and manipulate the digital audio playback accordingly as shown in Fig. 1. Using modern smart phones as a prototyping platform gives similar benefits as TCV, but provides numerous additional benefits including added visual display, multi-touch interaction, and untethered performance (e.g "air-scratching"),

NIME'11, 30 May–1 June 2011, Oslo, Norway.

turning a vinyl record into a familiar, but new tangible interface [19]. Informal testing shows promising results, with minimal latency and comparable feel when matched against alternative approaches[1].

2. RELATED WORK

Alternatives to commercially available digital DJ methods include various form factors and implementations. Bill Verplank references former students Keatly Halderman, Daniel Lee, Steve Perella and Simon Reiff replacing an existing phonograph needle with a riding wheel equipped with an optical shaft encoder to digitize the gesture control [30]. Hans and others developed DJammer, an accelerometer equipped MP3 player [27, 12, 13, 14]. In addition to untethered control of DJ gestures, DJammer presented the use of virtual jam sessions to exchange and share music audio streams. Sile O'Modhrain discusses the importance of haptic feedback for musical instrument design in [24] and emphasizing such importance, Beamish created the D'Groove haptic turntable device in [5].

The use of wearable sensors for real-time music signal processing is presented in [21], while an overview of designing alternative tools for turntable music in the digital era is presented in [22]. Villar et al. introduced the ColorDex DJ System [31], using color as a mixing metaphor. Hansen et al. have done extensive work on the acoustics and performance of scratching [17, 15] as well as high level gesture control [16, 18].

Multi-touch interfaces have also been used within many musical and DJ applications including the popular Reactable [20] and numerous commercially available DJ applications. A gesture based mobile music game involving touch-screen scratching was presented [11]. Most recently, Savage et al. introduced a multi-modal mobile music mixer using mobile phones with accelerometer for gesture control of Bluetooth streaming audio [26].

Surveying such past academic work emphasizes the various important differences in approach when designing new turntable interfaces. Firstly, there is a distinction between interfaces which are meant to enhance the turntable performance experience while maintaining the traditional physical interaction of manipulating motor movement versus interfaces which are meant to alter the interaction with equivalent audio effect. For better or worse, the goals between the two approaches are notably different. Secondly, there is a difference between the DJ performance practices of mixing and scratching. A large number of alternative interfaces focus on mixing because of the latency and sensitivity requirements. Scratching, described as the art of manipulating a vinyl record against a turntable needle, as well as the related scribbling (rapid scratching) [17] requires accurate, low-latency, highly-sensitivity sensing.

3. APPROACH

Within the various approaches found in recent and past research, we present work towards the *enhancement* of the turntable performance using existing analog turntable hardware. In addition, we focus on digital scratching interaction. As a general approach, we begin by leveraging the portability and computing power of modern mobile phones (or smartphones), which have been shown to provide a highly expressive compact form factor [32, 23]. Alternative sensors such as a wirelessly enabled light sensors or similar have the ability to offer a more compact form factor for rotation sensing, but do not provide numerous other advantages provided by modern smartphones.

[1]http://ccrma.stanford.edu/~njb/research/turntable/

3.1 Accelerometer and Gyroscope Sensing

Accelerometer and gyroscope–equipped smartphones, in particular, can be used to sense and wirelessly transmit gestural control data. With proper processing, a three-axis accelerometer and gyroscope can detect three-axis rotation rate (pitch, roll, and yaw velocities) ideal for sensing motion on a turntable. As a result, by firmly attaching a properly equipped mobile phone atop a vinyl record, an existing analog turntable can easily be modified into a digital scratching interface requiring no specialized sound card. Such a method maintains a near equivalent sense of tactility and results in a wireless sensing-based scratching method as seen in Fig. 2. Further, the wireless sensing method does not have any length limitation as found with TCV and advantageously avoids physical interference of the turntable tone arm.

Figure 2: Wireless Sensor Record In Action. A prototype record (combination of mobile phone, sticky rubber, and plexiglass disc) resting on a standard, commercially available turntable.

For many situations, the capabilities of accelerometers and gyroscopes are not ideal. The processing required is non-trivial and demands careful attention. Small errors in acceleration measurements propagate to larger errors in velocity and position estimates, commonly referred to as drift or bias. Gyroscopes, however, provide a complementary measure of orientation and can be used to improve accelerometer measurements via complimentary filters, statistical filters (i.e. Kalman filters), or other methods collectively referred to as sensor fusion algorithms. In addition, physical constraints can be added to further improve estimates such as limiting the axes of measurement. Serendipitously, the motion of scratching gestures are limited around a single axis and even more so, the motion is circular, directly relating centripetal force (provided by the performer) to rotational velocity. As a result, the use of accelerometer and gyroscope–equipped smartphones for precisely sensing scratching gestures is surprisingly suitable.

3.2 Proposed Method

By processing the continuous data stream of the accelerometer and gyroscope, the system can achieve a precise and robust measurement of instantaneous rotational velocity. This allows us to robustly track both steady and variable rotational velocity. Remarkably, this works well even for more extreme changes in rotational velocities such as those produced by the physical gesture of scratching. By transmitting this data over a low-latency wireless network, the physical gestures applied to the mobile phone can be mapped to the playback position of an audio file or, more generally, any other real-time audio parameter. This creates a viable alternative to prior digital scratching methods.

4. INTERACTIONS

The proposed method enables a number of additional benefits and novel interactions, taking advantage of multi-touch displays as well as the physicality and mobility of the modern mobile phone.

4.1 Visual Feedback

By placing a mobile phone on top of the moving vinyl record and adding real-time "on-record" visual feedback with multi-touch interaction, a simple vinyl record is transformed into an interactive surface. This can aid a performer in numerous contexts including cueing, scratching, and beat juggling. The processing of cueing involves preparing one record to mix in with another and involves matching tempo, musical phrasing, or similar musical properties. Direct visual feedback on the record can help in this process, even suggesting how to modify the speed controls of the analog turntable.

When performing scratching and beat juggling, DJs will typically place a visual marker (e.g., tape, paint, Post-it, etc.) to remember the playback point within a certain song as described in [5]. Having on-record visual feedback can directly aid in this process. Fig. 3 shows an example implementation displaying the actual audio signal itself on the moving record, visually displaying the current position within a song. As the record moves, the visual display is updated according to the exact position of the audio file playing on the host computer with the window size or length of the displayed audio controlled using multi-touch pinch-to-zoom controls. As seen, the start of a percussive sound

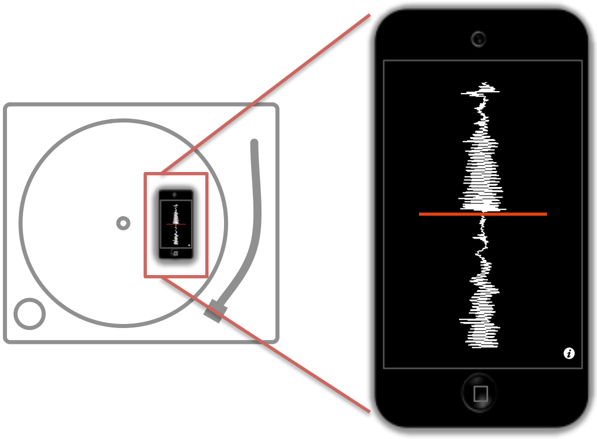

Figure 3: On-Record Visual Feedback. An example of on-record visual feedback displaying the time-domain audio waveform via custom software.

is displayed indicating a possible physical location within the record for scratching or beat juggling. More detailed visualizations could display virtual paint markings, tape, or Post-its for a familiar style indication or entirely different information and graphical user-interfaces. In addition, a performer could use such visual feedback to select the "needle" position within a song or even switch between multiple songs. As multi-touch technology advances, one could image a multi-touch display covering the entire record surface.

4.2 Gesture Modification

By using digitized gesture control, alternative gesture-to-sound mappings are possible. As standard in digital DJing, this can be found in the form of independent sensitivity, pitch, and tempo control. More specifically, scratching gesture can be *amplified* or *dampened* by scaling the transmitted rotational rate accordingly.

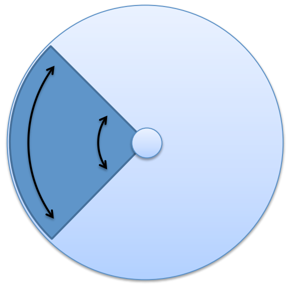

Figure 4: Changing Tone Arm Position Affects Gesture Sensitivity. The changing tone arm position affects scratching gestures as a function of line area.

As an alternative interpretation, sensitivity control can be seen as controlling the tone arm position within a record. Traditional analog turntables operate with constant velocity rotation, forcing audio material on the inner grooves of a record to correspond to proportionally longer length signals for an equivalent angle as seen in Fig. 4. This causes an exactly repeated scratching gesture to sound differently depending on the tone arm position. This effect can either be replicated or removed depending on personal preference.

In addition, gesture sensing can be set relative to still or constant motion. This allows the system to be used with or without the turntable motor in action. The measured rotation speed can simply be biased so still motion corresponds to a playback rate of 1.0 instead of 0.0, allowing the performer to choose his or her preference. This is not possible with traditional TCV, which requires active rotation.

Finally, as presented in [25, 8, 9] and others, such gestural control can also be used for *active listening*, allowing the general public of listeners and inexperienced users interact with the music generation and manipulation, not just trained musicians.

4.3 Untethered Scratching

While serving the purpose of enhancing traditional scratching gestures tethered to an existing analog turntable, the presented approach affords alternative interactions that can lead to new forms of expression. In particular, untethered or "air" scratching can be performed by simply lifting the mobile phone-equipped record off the turntable as no physical sensor connections are required. As discussed in [27] and [26], untethered interaction frees the performer to move about and even interact directly with the audience. Such ability poses numerous interesting questions regarding improvisation techniques and other musical devices. Involving audience participation during a live scratch performance, for example, is an appealing direction of study.

5. IMPLEMENTATION

For implementation, custom software for both the sensing smartphone and host computer was needed with minimal custom hardware. More detailed hardware and software implementation issues are discussed in §5.1 and §5.2 respectively.

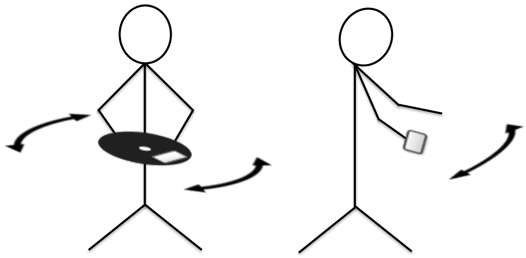

Figure 5: **Untethered Scratching Interaction. "Air-Scratching" is possible with or without a physically attached record.**

5.1 Hardware

For hardware, a single mobile phone, piece of sticky rubber, and plexiglass disc were used for each wirelessly enabled record. Fourth generation iPod Touch or iPhone 4 devices were found to work well. Both devices include a three-axis accelerometer and three-axis gyroscope with a maximum sample rate of 100 Hz as well as a multi-touch display and wireless networking capabilities. The iPod Touch is physically thinner than the iPhone 4 and found to be slightly preferable. In order to firmly attach the device to a vinyl record, sticky rubber is placed in between the record and mobile device as shown in Fig. 6. Commercially available rubber mats (used to hold mobile phones against a car dashboard) were used and found to be sufficiently sticky.

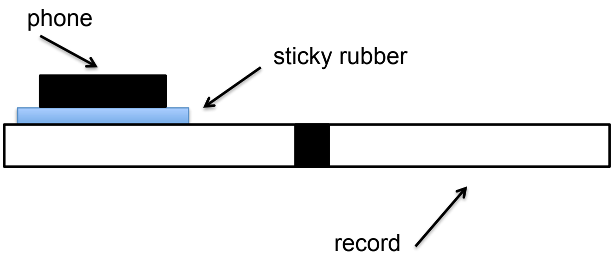

Figure 6: Wireless Sensor Enabled Record. A mobile phone attached to a modified record via sticky rubber.

Various plexiglass discs were used in place of a vinyl record. By varying the weight and size of record, a performer can customize the drag or friction between the record and slipmat to suit their needs. A collage of prototype images is found in Fig. 7, showing a single record with phone and rubber, collection of various discs, and the complete DJ setup.

5.2 Software

Software implementation came in two forms: software on the mobile phone and host computer software. The mobile phone software was written within Apple's iOS SDK along with portions of the Mobile Music Toolkit [7], oscpack [6], and the Synthesis Toolkit [10]. The iOS CoreMotion framework gives an excellent mechanism to stream processed accelerometer and gyroscope data by an unspecified sensor fusion algorithm (most likely complementary or Kalman filtering), directly providing three-axis rotational rates of pitch, roll, and yaw. The yaw rate is then wirelessly transmitted using Open Sound Control on top of UDP sockets. Track information and other non-real-time information can be sent reliably over TCP sockets.

Figure 7: Prototype Hardware. (Upper Left) Phone, plexiglass disc, and sticky rubber. (Upper Right) Various sized and weighted discs to accommodate a performer's sense of tactility. (Lower) Prototype setup.

To adequately implement the visual feedback of the currently playing audio stream as discussed in §4.1, additional information including the position within the currently playing audio file must be sent from the host computer back to the mobile phone to update the display. If the visual display is not updated by the host computer, the two devices will drift from one another causing the audio and visuals to become out-of-sync. Such effect is confusing to the performer and is greatly undesirable.

Host software employs the Jules' Utility Class Extensions (JUCE) [29] providing a cross-platform framework with numerous tools ready for audio application development. A traditional DJ software model is taken, allowing two simultaneous audio streams. The host program receives the transmitted rotational rate and manipulates the audio stream by resampling. Linear interpolation was initially used for prototyping, with improvements found when using higher-order polynomial interpolation [28]. An image of the developed software is shown in Fig. 8.

Figure 8: Custom Prototype DJ Software. The developed DJ software required to receive and processing the mobile phone sensor data and manipulate audio accordingly.

6. DISCUSSION AND EVALUATION

As discussed earlier, there are various advantages and disadvantages when comparing different digital scratching methods. In general, however, it is difficult to objectively evaluate new methods and compare against past work. Just as a violinist gets a custom to the feel and sound of their instrument, a DJ will learn the subtleties of a given scratching method and can be averse to change [5]. Informal performance testing, nevertheless, showed promising results with minimal perceived latency between input gesture data and output audio playback.

General measures of evaluation included precision and responsiveness as well as stability. Rapid physical gestures were seen to be very responsive and have precise corresponding audio effect. Repeated physical gestures were also found to have a consistent sounding effect over long performance times. Further testing with professional level DJs, however, is needed for a more complete evaluation. For a video demonstration of the system in action please see `http://ccrma.stanford.edu/~njb/research/turntable/`.

The one-way network latency time between a given phone and host computer was measured to be on average 3-5 ms and compares favorably with professional audio recording equipment. When comparing the maximum humanly-possible scratch rate (10-20 turns per second [17]), the 100 Hz sample rate of the accelerometer and gyroscope appears suitable. The perceived effect of accelerometer and gyroscope latency, however, is difficult to measure and dependent on the sensor filtering method used, requiring further study and user evaluation.

7. CONCLUSIONS

A straightforward and surprisingly effective method of digital scratching is presented. The proposed method leverages existing analog turntables as a physical interface and takes advantage of the capabilities of modern sensor–equipped smartphones, resulting in a genuinely physical, wireless sensing-based scratching method. Benefits include digital audio and storage, minimal additional hardware, familiar proprioceptive feedback, and a single interface to control both digital and analog audio. Further benefits include visual display, gesture modification, and the possibility of interactions untethered from the turntable. Testing and evaluation show this approach to be viable and promising.

8. ACKNOWLEDGMENTS

This work was enabled by National Science Foundation Creative IT grant No. IIS-0855758 as well as the funding from the School of Humanities and Sciences, Stanford University. Additional thanks to Professor Jonathan S. Abel for valuable conversation regarding the tone arm control. Finally, a thank you to the anonymous reviewers for valuable feedback regarding the application of active listening and track switching, among other observations.

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