Digiti Sonus: An Interactive Fingerprint Sonification

ABSTRACT
Fingerprints are one of the most unique visual patterns in human body. It represents both innate and acquired identities of an individual. In this paper, we focus on relationship between fingerprint patterns and human identities by transforming image into audio. Digiti Sonus, an interactive fingerprint sonification installation, contains a novel idea to facilitate and enhance an interactive auditory meaning by transforming user-intended fingerprint expression into audio spectrogram. In order to enable personalized sonification, the installation employed dynamic filter generation based on minutiae extraction using core-invariant scanning method and image skeletonization.

Categories and Subject Descriptors
H.5.5 [**Information Interfaces and Presentation**]: Sound and Music Computing – s*ignal analysis, synthesis, and processing*; I.5.5 [**Pattern Recognition**]: Implementation – *interactive systems*, and; J.5 [**Computer Applications**]: Arts and Humanities – *fine arts*.

General Terms
Algorithms, Design, Experimentation, Human Factors.

Keywords
Interactive multimedia art, fingerprint sonification, fingerprint image processing, heterogeneous data interpretation.

1. INTRODUCTION
Every biologic organism has a unique body pattern. Among all the patterns, fingerprints are the most unique visual patterns in human and primates' bodies. There are only few graphical line patterns in human body such as wrinkles of hand, elbow, and knee, and palm lines. Rather than the others, fingerprints are the only clearly recognizable patterns that can be manipulated and saved into large amount of database. Because of the clarity and uniqueness, fingerprints have been widely used for personal identification. In this digital era, many computer machines and digital interfaces use fingerprints as secure keys and access to identify personal information. Fingerprint identification is one of the most significant biometric technology which has drawn a substantial amount of attention.

Fingerprints are naturally generated biometric pattern that can represent both innate and acquired identities of an individual. Fingerprints are fully formed based at about 7 month of fetus development [2]. Original pattern of fingerprints do not change throughout the life of an individual except due to accidents. The finer details of fingerprint is decided based on microenvironment that has combination between genes and environment [2]. Changes of fingerprints throughout lifetime can show acquired identity with history and environmental influence. Thus, an individual's fingerprint can be used for examining personal identity based on biometric information and unique visualization.

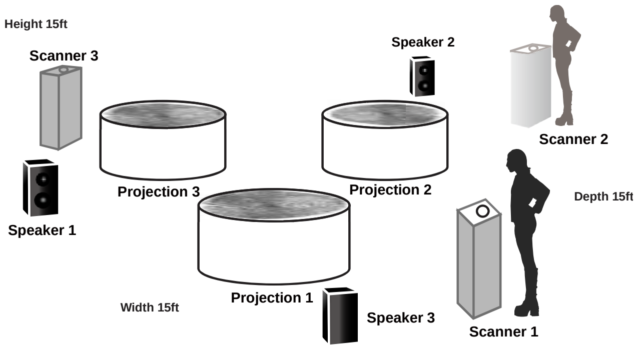

Figure 1. Digiti Sonus Installation plan.

In this paper, we focused on relationship between fingerprint patterns and human identities by using audiovisual experience and integration of image and sound. The overall fingerprint patterns from people are mostly similar, however the detailed difference between fingerprints can be determined by observing the local ridge characteristics and their own relationships [3]. We would like to enlarge the minor details of ridge characteristics, called *minutiae*, which are not easily recognized by naked eyes. It pursues to increase the impact of natural body pattern and beauty of nature. Furthermore, in a final installation, visual elements are transformed into auditory results in both artistic and scientific ways so that audience can observe their own identities by hearing sound generated by their own fingerprints. Since the process to transform visual pattern of fingerprint into sound, the *fingerprint sonification*, is rarely documented in past approaches, our purpose in this paper is to offer both an artistic experiment as a result of an interactive audiovisual installation and a scientific approach to realize a new kind of biometric data sonification. To the best of our knowledge, this is the first attempt to bridge the gap between fingerprint and sound, so that it can be a novel approach to address a new way of interaction using biometric data in new media art, and new scientific application.

2. RELATED WORK
There have not been closely similar approaches about biometric data sonification as artistic forms. However, some researches showed their own novelty and relations in either artistic context or technical improvement.

2.1. Fingerprint image enhancement

Fingerprint image enhancement shows effective ways to enhance the quality of input fingerprint images by using minutiae extraction algorithm [4]. Irregular and unclear fingerprint image can be restored well in this research. The method, using and manipulating ridge ending and ridge bifurcation, is useful to analysis the pattern of fingerprint and we adopted its visual feature extraction in this paper.

2.2. Sonification of Faces

Sonification of faces presents a system which allows visually impaired people access to some of this information by means of sonification [5]. Face is the most fundamental point of human body for interactions. Therefore its sonification can be one effective method to convey body information to blind/partially sighted people and to enhance person interaction. The goal of this research has close connection to this paper since delivering personal identity through body data is the most significant part for realizing better human communication.

2.3. Orchestral Sonification

Orchestral sonification presents real-time sonification of Electrical brain signals (Electroencephalogram, EEG), referred as *brainmusic* [6]. The final output describes possibility to apply sonified physiological signals to performing arts in different ways. This work shows creative ways to incorporate real-time brainwave data to immersive sound environment in artistic form. Compared to 2.2 Sonification of Faces, orchestral sonification discusses all the unified connection of human body oriented to brain and sonification of detailed body artifacts and brain all together.

2.4. From metaphor to medium: Sonification as extension of our body

This paper argues that use of sonification should be not only in the area of creating aesthetic experiences related to data, but in the expansion of cognitive models available to the actively exploring listener[7]. The conscious strategy to approach the perception of sound should be in the same manner with implemented data. Since sound is a vibration of air to approach human body, sonification (non-visual data) should be much stronger than visual data in terms of cognitive response and conscious perception.

Since Digiti Sonus has partly related connections to works presented above, different strategies from related works are needed in both technical and contextual adoption. The advanced technical development of fingerprint image enhancement should be investigated for the better pattern extraction. Different approaches and results from sonification of face and brain are considerable for an expansion of body sonification. And as an artwork that should realm audience's body and mind, the novel concept of sonification as extension of our body is much needed. However, fingerprint sonification is a novel and unique strategy to present both body data and cognitive identity without any previous researches and works. Therefore, it should be developed independently as a leading research in sonification.

3. INTERACTIVE SONIFICATION

3.1 Fingerprint Acquisition

Basically fingerprint can be acquired by using all kinds of equipment such as image scanner widely used in home and office and fingerprint sensor implementation. The main difference between home scanner and fingerprint sensor is the former is developed for scanning most objectives such as documents,

Figure 2. Visual feature extraction of fingerprint sample from FVC2004 dataset. Image skeletonization and minutiae analysis are applied to find singular points on fingerprint.

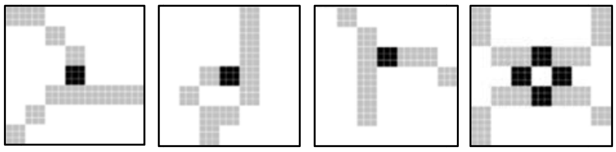

Figure 3. The examples of four major singular minutiae in our fingerprint image analysis approach. (a) Bifurcation, (b) lake, (c) spur, and (d) crossover.

business card and photos. Thus, it is not specified to recognize the content of scan objects, however, it may scan contents with minimum enhancement such as color map transformation, noise reduction, or sharpening/blurring. For specific purposes, therefore it requires additional implementation, e.g. minimizing the size of OCR sensor for the only purpose to scan fingerprint. Otherwise, the latter, fingerprint sensor, is implemented only for specific purpose such as security detection rather than providing ordinary scan functionality. For example, the fingerprint sensor, mostly and widely used for security purpose, detects singular features from human fingerprint and generates unique identifiers for human-specific identification. However it cannot provide generality because of its primitive and limited objectives.

Meanwhile, a user generally provides fingerprint by touching his/her fingers onto the sensor. In this process, the user can express his/her only purposes by varying touching pressure and contact extent, e.g. pushing hardly and giving large contact extent of fingerprint, or pushing softly therefore giving only partial portion of a fingerprint. In order to obtain user's intention via fingerprint image acquisition, it is significantly required to obtain pressure- and extent-variant. As aforementioned, widely used home scanners can acquire fingerprint without rare modifications other than specific image processing. On the other hand, commercial fingerprint sensors can detect human-specific unique features from input fingerprint image, whereas it usually ignores the touch pressure and contact extent. Thus, we implemented a fingerprint-specific scanner for obtaining essential features to this end.

3.2 Visual Feature Extraction

As aforementioned in section 3.1, user expresses his/her hidden intension via varying touch pressure and contact extent of fingerprint. In order to extract user's intention as well as widely-used fingerprint-specific features, it requires additional visual feature extraction based on image processing.

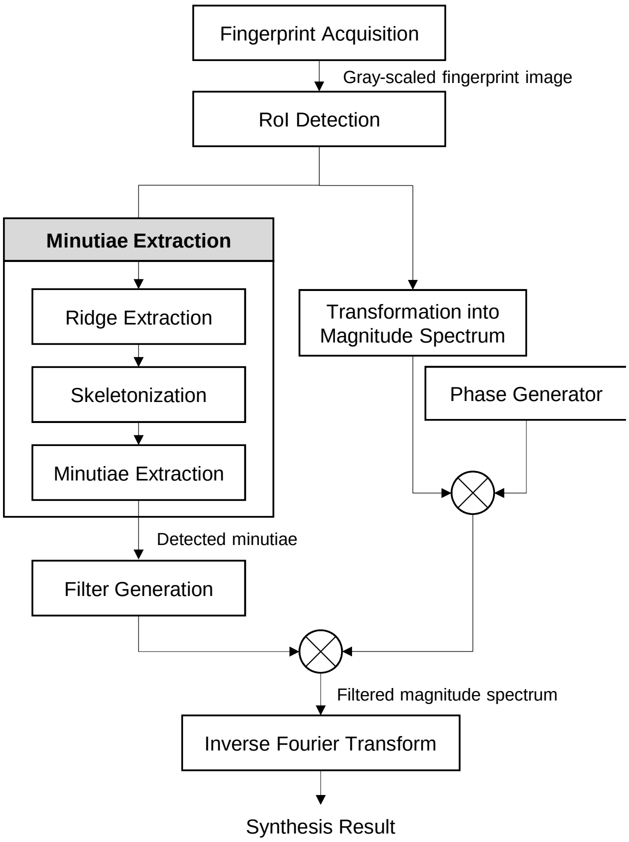

Figure 4. Overall fingerprint sonification process.

Fig. 2 depicts how to extract basic visual features from the obtained fingerprint image. First, gray-scaled fingerprint image is processed by thresholding the intensity of image. This step is required to discriminate ridges and valleys of fingerprint. The next step, skeletonization, is for eliminating pressure-specific information from fingerprint. For example, if the fingerprint was inputted by high touch pressure, more ridges can be appeared other than the portion of valleys decreases. This difference caused by pressure variation can affect overall fingerprint sonification task. To this end, image skeletonization is applied on ridges, black lines in fig. 2(a) thresholded image, in order to normalize the portion of ridges and valleys as fig. 2(b). Finally, singular points among detected ridge skeletons, the minutiae, can be detected by tracing and distinguishing branches. In our approach, we detected 4 singular minutiae, which are bifurcation, lake, spur, and crossover[2] as shown in figure 3. Because of the uniqueness, the extracted features are human-specifically identical and being widely used in human identification based on fingerprint sensing system.

3.3 Fingerprint Sonification

A singular point extraction of fingerprint in section 3.2 is one of the hints to define user-specific singular points or area in fingerprint image. This is a significant basis of our fingerprint sonification approach, that is, the sonification results in our system are varied by user-specific features.

Most human fingerprints are classified into left/right loops, whorl, arch, and tented arch types, and they have its own core, which is the origin of starting fingerprint analysis. However, there are still unemployed user expressions such as pressure and contact extent.

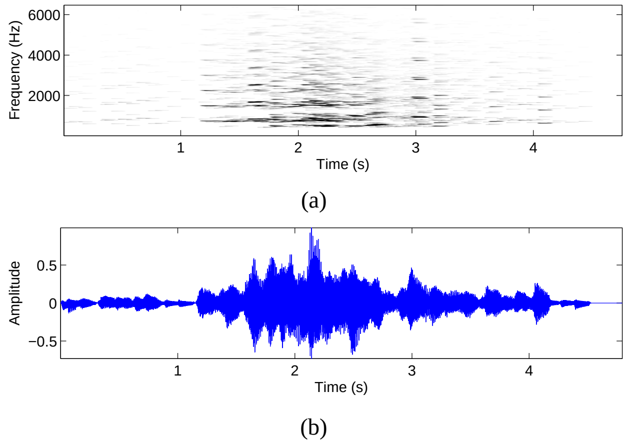

Figure 5. (a) A magnitude spectrogram and (b) wave sequence sonified from fingerprint.

Since user can freely input only a partial extent of entire fingerprint, core of fingerprint can be omitted. Consequently common fingerprint analysis approaches based on core origin extraction are not applicable in our approach.

In order to gather information regarding singular points only, one-directional scanning is employed in our approach. The one-directional scanning approach assumes fingerprint having two main axes: temporal axis and magnitude axis. For example, fingertip is the origin as known as time zero in temporal axis representation. On the other hand, magnitude axis usually depicts 'magnitude' itself such as power, quantity, and amount of some measures. In fingerprint sonification a user expresses his/her intensity by touch pressure, consequently the portion between ridge and valley is proportional to sound intensity: portion of ridge increases with higher pressure, otherwise it decreases. Furthermore, user can interactively modify his/her touch pressure input by sonified fingerprint as the feedback. For these reasons, our approach transforms portion between ridge and valley into magnitude values to represent them in magnitude axis.

Figure 4 depicts overall fingerprint sonification process including fingerprint acquisition and its preprocessing. After fingerprint acquisition appeared in section 3.1 and minutiae extraction explained in section 3.2, sound filters generated by extracted minutiae are applied to transformed fingerprint image into time-magnitude axes. In this step, sound filter represented in frequency-domain can be anything such as traditional low-/high-/band-pass filters or some user-defined function. Here fig. 5 displays final magnitude spectrogram of a fingerprint input and its inverse-transformed wave sequence.

4. IMPLEMENTATION OF DIGITI SONUS

This section describes how to implement Digiti Sonus in a physical art gallery space. The processes to set up equipment and to analysis the fingerprint images through software are discussed.

4.1 Concept and Scenario

Digiti Sonus is planned to install in an art gallery space or any other possible space with related theme. The ideal dimension of the space is width 15ft x depth 15ft x height 15ft as Figure 1 depicts. Users may have pre-informed knowledge about the installation before entering the gallery space. When a user enters to the space, he or she can see three stations containing finger print scanners. The user can easily understand where to touch their fingers on the screen based on instructions and intuitive

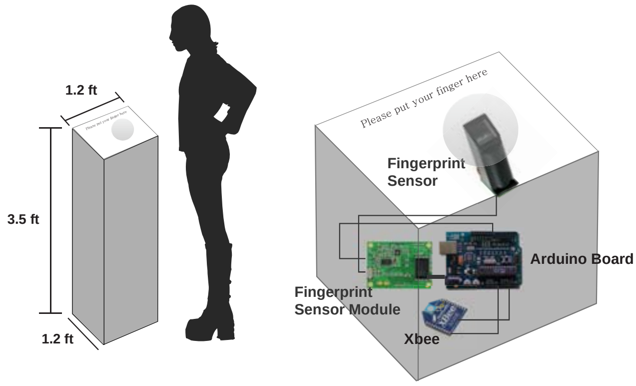

Figure 6. Fingerprint scanner structure.

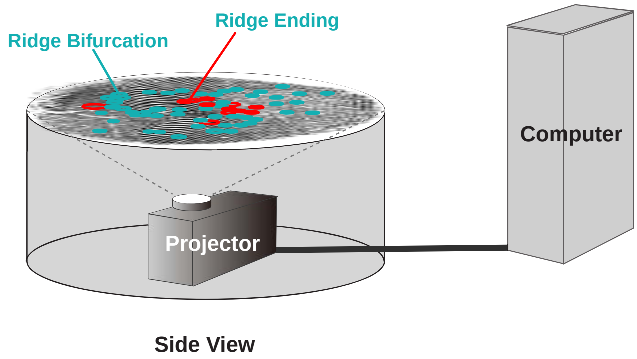

Figure 7. Circular projection box design.

interface design. As soon as finger print images are saved in computer, the enlarged finger print images are appeared on a circular projection on the floor, and the user can recognize the communication between the scanner station and the projection space. Based on fingerprint extraction and minutiae analysis discussed in section 3, positions of minutiae on the projection are highlighted with red and blue colors so that the user can easily recognize the specified points of sonification analysis in real time. In a short moment, sound generated by handprint image is played through a single-channel audio system, and it is sequenced over time. Multiple users can participate in creating sound in real time in order to experiment their own fingerprint sound and make multiple sequencing sound. As a result, three-channel audio systems along with three visualization respectively are harmonized within repeated sequence. In a gallery space, eventually, users can explore how their and other people's fingerprints are all converted into sound in real time. The audiovisual experience based on biometric data transformation immerses audience and shows the relation between audience's participation with their bodies and audiovisual elements.

4.2 Hardware and Software Requirements

Figure 6 and 7 describes how a fingerprint scanner machine and a projection box is designed and installed. Nitgen RS232 serial fingerprint scanner [1] is connected to Arduino-based microcontroller board [2] for transferring the acquired fingerprint data to computer. It transfers the data to main computer through wireless network. Each station generates its own differentiated signal so that it is possible to achieve three distinct fingerprint acquisitions. The main computer keeps saving the acquired users' fingerprint as well as minutiae extracted from fingerprint described in section 3.2. Next, the extracted minutiae data are transformed into sound as mentioned in section 3.3. The surface of a circular projection is a semi-transparent paper that can projects the enlarged fingerprint image in grayscale and minutiae points in red and blue colors. The red and blue dots are highlighted when passing it over time as sound plays. This allows users to easily and intuitively understand which part of the image is being played in real time.

5. CONCLUSION

Sonification is an effective method to convey information, especially when the information only contains visuals and is not possible to be read in human sight. In this research, we proved that one of the body organ patterns, the fingerprint, could be expressed as sound with user intension. Digiti Sonus, an interactive fingerprint sonification installation, contained novel idea of fingerprint sonification which facilitates and enhances an interactive auditory meaning by transforming user-intended fingerprint expression into audio spectrogram. In order to enable personalized sonification, the installation employed dynamic filter generation based on minutiae extraction using core-invariant scanning method and image skeletonization. As the future work, fingerprint can be analyzed in diverse ways in considering the enormous potentials in discovering new ways of sonic expressions as an art form, scientific research, or educational material.

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