Mobile DJ: a Tangible, Mobile Platform for Active and Collaborative Music Listening

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ABSTRACT
This paper presents *Mobile DJ*, a tangible, mobile platform for active music listening, designed to augment internet-based social interaction with the element of active music listening. A tangible interface facilitates users to manipulate musical effects, such as incorporating chords or "scratching" the record. A communication and interaction server further enables multiple users to connect over the Internet and collaborate and interact through their music. User tests indicate that the device is successful at allowing user immersion into the active listening experience, and that users enjoy the added sensory input as well as the novel way of interacting with the music and each other.

Keywords
Mobile, music, interaction design, tangible user interface

1. INTRODUCTION
Mobile DJ is a music-listening system that allows multiple users to interact and collaboratively contribute to a single song over a social network. Our platform enables single or multiple users to actively modify music content or manipulate sound effects via a physical interface device, which supports multiple modes of interactions, and encourages user immersion into the music through exaggerated physical motions.

Our system also allows collaborative and social interaction in real time, regardless of the users' location. It also allows players to browse and search sound tracks that are currently being worked on by others, and provides a channel for them to collaboratively contribute. Such collaboration requires synchronization of actions, even when the users are in different physical locations, in order to achieve pleasant effects.

Preliminary user testing with 9 people showing that *Mobile DJ* can effectively establish a collaborative musical network, through enhancing the interactional synchrony and rapport between users.

2. MOTIVATION
In recent years, social networks have changed our life style by connecting and bonding people with friends and family, as well as people who share the same interest. Much of this activity is directed through text or graphics, such as status updates and photo sharing.

Active music listening [19] enables users to interactively mold and modify the music they are listening to in real time. Such interactions allow the users' active participation to influence the music listening experience. The expectation is that this interaction with the music would lead to stronger engagement and musical embodiment on the part of the user.

Mobile and wearable devices have become almost pervasive in recent years. These devices offer the possibility of social and collaborative interaction in different locations and situations. Riding on the success of mature sensory systems and well-developed hardware technologies, mobile devices nowadays possess processing power that is capable of handling multimodal and multimedia interactions. This integration of mobile devices offers the possibility of an embodied dimension and richer social network interaction.

We believe that there is much room for further study on the effect of active music listening on social networks over mobile devices and on the enhancement of social bonding by collaboration and physical efforts in interaction. Our *Mobile DJ* platform is a step in this direction.

3. RELATED WORK
Tangible interfaces are an inspiring research topic for many disciplines, especially in human computer interaction, as they can effectively facilitate intuitive and direct manipulation. CoolMag [28] applied a series of magnetic sensors to detect the touch of a user's fingers, which allowed users to adopt objects in daily life as carriers of musical instruments. Ubiquitous Drums [26] embedded multiple force sensors on clothes, which enabled the user to generate drumbeats using percussive gestures. These applications focused either on the design of a particular instrument or on a single user's experience without the involvement of social collaboration. Freqtric Drums [3] used electric current to turn the audience into drums. It required all the users to hold the device, which implies its necessity for face-to-face interaction. Similarly, Jam-O-Drum [4] was an interactive musical system, which allowed multiple users to play and collaborate simultaneously. However, it was based on sharing a single surface, and not intended to facilitate remote social interaction.

There has also been much work in active music listening, deploying various techniques such as such as computer vision and wearable sensors [8, 9]. Examples of interactive sonification systems include gesture-based music synthesis as well as motion-based synchronization [25]. Active music has also been used for dance music generation [7] and sport training [9,10,11].

Research into social interaction through active music listening is still in its infancy. Investigations originating from the low level (e.g. motion rhythm) single user-centric active listening has recently focused on the listening interaction between multiple users and the corresponding high level expressive and emotional processes. Stokholm [27] applied reinforcement learning to enhance the users' mood and mixed audio to increase collaboration and empathy among the users. Varni [22]

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noticed a positive correlation between phase synchronization and social interaction empathy and dominance. They also developed a multi-channel musical system to explore the effectiveness of user centric media on mobile phones in affecting the social interaction and synchronization [24]. Three different interactive sonification methods, generating music according to the users' motion coordination metric, were introduced and compared [23]. By linking the musical attributes with the human motion, researchers observed a correlated effect of the audio stream on users' synchronization of rhythmic motions, entertainments, empathy, and collaborative social behaviors.

Interactional synchrony covers the elements of temporal coordination, interpersonal communication [6] and emotional contagion [14] in social interaction. It is believed to have a strong connection with rapport for nonverbal human interaction, which is crucial for trust, closeness, and acknowledgement [21]. Interactional synchrony originated in psychology was applied in human robot interaction [1,17,18]. Motion rhythms were used as an important way to enhance the interactional synchrony during interaction. Michalowski et al. [18] developed a rhythm-driven robotic system, which provided the user with visual feedback of synchrony during the interaction, demonstrating the enhancement arising from interactional synchrony. The study of Shadowplay, a robot human interface trained with real human-human interaction data, showed the effectiveness of interactional synchrony, imitation and correlated sequences of behaviors during interaction [17]. Other applications also indicated the value of interactional synchrony. Gait alignment has been detected and augmented to facilitate interactional synchrony during mobile phone conversation [19]. Balaam [2] introduced an ambient display to enhance the interactional synchrony, which was proved to have an influence on the participants' nonverbal behaviors.

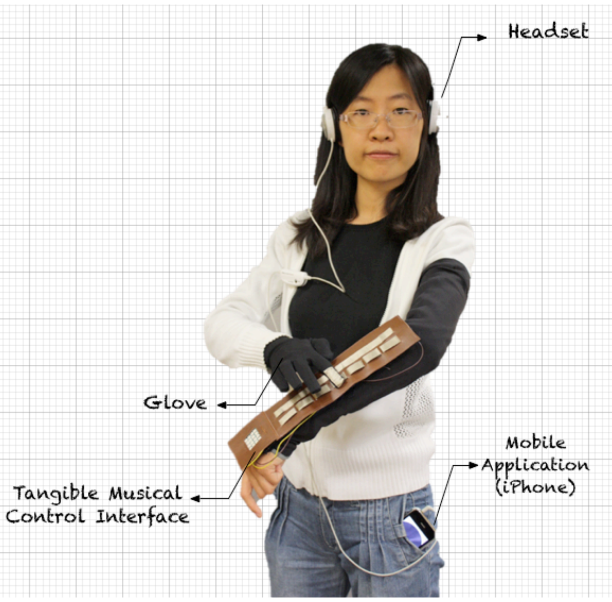

Figure 1 A *Mobile DJ* user

We believe by investigating the designs of social interaction factors, we can apply the positive effects on social interaction from tangible interaction, active music listening, and interactional synchrony, to establish a collaborative social music network that would encourage social bonding and engagement.

4. DESIGN CONCEPT

Figure 1 shows a user wearing the *Mobile DJ* device, which consists of a tangible musical control interface that is connected to a mobile device for signal processing and social interaction.

In *Mobile DJ*, musical control can be divided into two functions: musical effect control and audio time-based control. Players can actively enrich the active playing track by inserting chords, changing instruments or rhythm while scratching is implemented to offer time-based control. The following section discusses the system architecture and interaction design.

4.1 System Design

The overview of the system architecture of *Mobile DJ* is shown in Figure 2. The system consists of three components: Tangible Musical Control Interface, Active Music Listening Application and Application Server.

The Tangible Musical Control Interface is responsible for capturing the user's interactions. Together with the mobile device, it forms a self-contained digital musical mixing platform. Active music listening on a single-user basis is enabled when a user connects the Musical Control Interface to device and registers it with the application.

The Application Server provides support for multi-user active music listening which implemented with i*Chameleon web services middleware [16]. It provides a comprehensive protocol to model and integrate the Musical Control Interface together. Portable music player, such as an Apple iPhone, that is running an Active Music Listening Application can be connected by standardized web services.

The prototype Active Music Listening Application was implemented to run on iOS in Objective-C, and the BASS audio library [5] was used to implement special sound effects such as scratching.

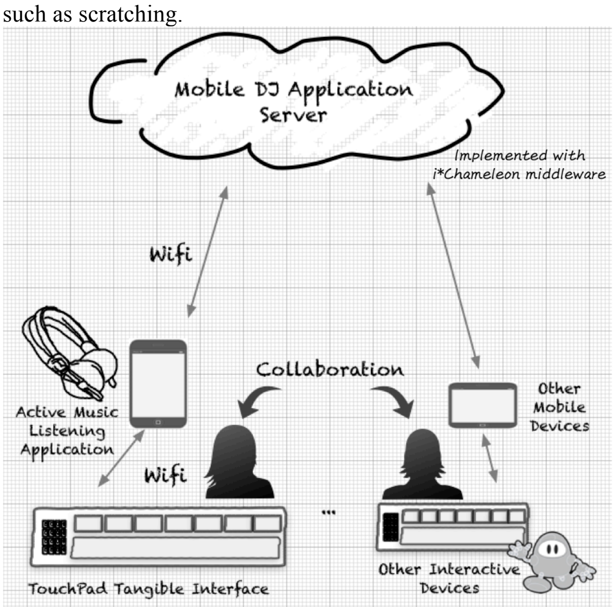

Figure 2 *Mobile DJ* system architecture

4.2 Tangible Musical Control Interface

The Tangible Musical Control Interface is intended to be portable, and, to a certain degree, wearable. We performed some preliminary user tests to gauge the intuitiveness of different form factors for the interface. The final prototyped design was a lightweight armband equipped with sensors, which would be manipulated by a gloved hand.

There has been some work in predicting social acceptance of a new interface through analysis of the user interaction [12,20]. Reeves [8] suggested using manipulations and effects to evaluate the design of public interfaces. This also fits in with our intuitions on the best way to facilitate the immersive experience of the user. Based on this conclusion, we designed our Tangible Musical Control Interface to have high degrees of manipulation and effect. In other words, we designed our interaction to require large scale of body motions, and to produce rich feedback and distinct effects.

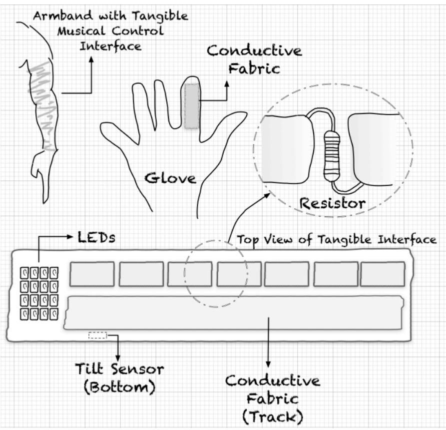

Figure 3 Hardware implementation of *TouchPad*

Figure 3 shows the hardware implementation of the interface. We required the interface to be intuitive and to support different modes of interaction with the music. From a wearability standpoint, the form factor of the interface as an armband implied that users should be able to interact with the music through movements of the other hand on the arm, or by swinging the arm. In addition, we wished to facilitate immersion into the musical listening experience by encouraging exaggerated interaction motions from the user.

4.3 User Interactions: Scratching

Moving a vinyl record back and forth to distort the melody and produce distinctive sounds is considered to be an art form in and of itself in hip-hop music. Traditionally, scratching requires a DJ mixer, vinyl record, and a turntable. The user physically interacts with the record by moving it forward and backward and butting the sound on and off with the crossfader [15].

The Musical Control Interface for *Mobile DJ* supports scratching through a slidebar potentiometer incorporated into the surface of the armband. The slidebar consists of two tracks. The lower track is in one piece, while the upper track consists of segments connected with constant-valued resistors. When a user touches both the upper and lower tracks at the same time, the resistance between the tracks changes in proportion to the number of resistors that have been bypassed, thus allowing us to determine the upper track segment that is currently being touched. For aesthetics and usability, the tracks in the potentiometer are constructed from conductive fabric, which makes them congruent to textiles and garments.

The connection between the tracks created some challenges. We designed a conductive glove to enable the potentiometer to better and more stably detect changes in the resistance. At the same time, wearing the glove on one hand enhances the user's immersive experience, similar to how stage costumes enhance the ability of actors to immerse into their character.

The user triggers a scratching interaction by sliding his/her hand over the tracks. The amplitude (number of sections that the sliding motion moves over), velocity and direction (up or down the arm) of the motion are mapped to angular displacement of the vinyl record, speed of the scratching motion and the direction of the motion. Our preliminary tests showed that an angular displacement of twenty degrees per track segment generated the best effect.

On the software side, the scratching effect is generated through dynamic audio generation by filling a playback buffer. When the user touches the two tracks, the segment is determined and the Active Listening Application maps it to an initialization position of the virtual record, the source stream of the playing music pauses and a "fill-audio-buffer" callback stream is started. As the user slides down the tracks, the scratching effect is generated by interpolating between the previous position in the scratch buffer and the current position.

Compared with "scratching" a virtual "record" on a mobile device touchscreen, the motion required by the Musical Control Interface is larger, and closer to the actual scratching motion performed on a vinyl record. We believe that together with interacting to the rhythm of the music, such interaction can enrich the experience of the player.

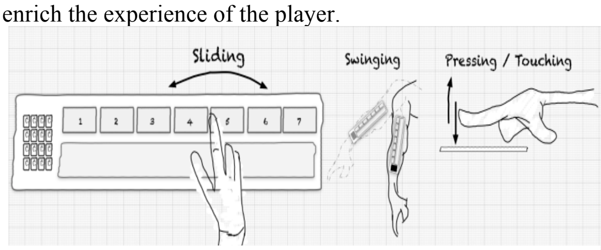

Figure 4 Interaction design of *Mobile DJ*

4.4 User Interactions: Swinging

Swinging, swaying and bouncing along to the beat is a common response to music, and certainly very commonly seen in active music listening experiences. The armband form factor of the tangible interface also suggested interaction through swinging or waving of the arm.

This mode of interaction is supported via the incorporation of a tilt sensor in the armband, which detects movements of the user's body. A low sensitivity filter is used to distinguish conscious movements, such as swings, waves and bounces, from normal movement.

In preliminary user evaluations, we observed that swings and waves of the arm were often used to communicate intentions in multi-user, remote collaboration scenarios. These intentions were often "handshaking" interactions, such as signaling the beginning or the end of a turn, or inviting the other user to begin his/her turn. These swings and waves are detected and communicated to the other users via the visual feedback mechanism to be described later.

4.5 User Interactions: Pressing

In addition to sliding, the slidebar potentiometer on the tangible interface also supports a pressing interaction. In *Mobile DJ*, the pressing motion maps to the enrichment of the musical track by interspersing the melody with chords and different instruments, or changing the rhythm and the harmony.

The interface supports both a short "tap" as well as a long "press". The "buttons" are the upper track segments. A tap on a "button" adds a chord to the music; the system will automatically generate an appropriate chord based on the key and the instrument of the currently playing song. Since we have seven "buttons", this allows the user to generate up to seven different chords. Long presses trigger a change in rhythm or harmony of the music in a similar fashion.

4.6 User Interactions: Visual Feedback

In general, in active listening, the user's interactions will receive audio feedback through the rearranged or modified music track. However, since one of the objectives of *Mobile DJ* is to support remote multi-user interaction, it was also deemed necessary to incorporate visual feedback to enhance the interaction between users.

The visual feedback is supported by a matrix of multicolored LEDs that is incorporated into the tangible interface above the slidebar potentiometer. The LEDs flash in different colors to signal interactions from the collaborating partner, which provides a channel that allows a certain degree of communication and signaling, but without interfering with the experience or imposing upon the center of attention of the user. In the absence of signals from the other party, or in single-user mode, the LEDs serve as an additional form of feedback to enhance user immersion by flashing along according to the rhythm of the music.

4.7 Support for Collaborative and Social Interaction

Table 1 Gestures and corresponding functions

Gesture	Duration	Section	Function
Sliding	-	1 – 7	Scratching
Pressing	< 1 s	1 – 7	Chords
	> 1 s	1 – 2	Changing Background Music
	> 1 s	3 - 4	Changing Chords Style
	> 1 s	7 - 8	Changing Instruments
Swing	< 1s	-	Indication of end of performance and it will reflect on other connected players

To support the social interaction between users, *Mobile DJ* includes a location-based, user discovery function, which allows users to discover other “unconnected” players nearby. For example, player A can see that player B, who is 500m away from him, is still unconnected, and invite him to join the music network. Once two players are connected, they share their chords and music. Both of them can manipulate the same background sound track by adding their own records. Additionally, each player can wield different effects, or can alternate effects, which provide for better effect on collaboration and socialization.

5. SYSTEM USABILITY

To explore the usability of *Mobile DJ* and investigate the ways in which the different system design factors affect the interaction style and collaborative effect, we conducted a task-driven experiment.

9 participants (6 male, 3 female) between the ages of 18-30 were recruited for this experiment. None of them had worked with the device before. 4 of them had prior musical training.

The participants were first given three minutes to explore the device by themselves, after which, a short tutorial was given to explain proper usage of the interface. They were then asked to spend around 5 minutes testing the device. Finally, they were given an iPhone running an application that could also simulate the same interactions (scratching, pressing and swinging), and asked to repeat their interactions with the phone. The experiments were all video-recorded for analysis. Post-experiment, the subjects were asked to compare the two systems, and post-experiment interviews were conducted for more in-depth investigations.

Our first observation relates to the initial posture chosen by the experiment subjects when they were given the devices, as this is likely to affect the manner in which they are used. For example, if the users preferred to sit while interacting with the device, the scale of motion would likely be limited. Interestingly, almost all of our users chose to interact with *Mobile DJ* in a standing position – which we noticed was not the case when they were presented with the mobile phone.

Almost all of the users were also able to discover the sliding and pressing interactions without any help. Surprisingly, however, none of them discovered the swinging/waving interaction during their explorations.

To evaluate the ability of the system to encourage movement during active listening, we used the skeleton model from the Kinect motion-capture camera to record the body motion in terms of human translation and joint variation. The motion was then quantified using the concept of motion energy, which is calculated as a weighted sum of movement levels of the body’s joints. We tracked the subjects’ joints’ locations throughout the experiment. At intervals of 100 milliseconds, we calculate the motion energy as $\sum w_i \cdot \Delta d_i$, where w_i and Δd_i respectively denote the weight and the spatial translations of the i^{th} joint. The weight of the torso and wrists is set to be 1.5 times that of other joints’, which allows the model to focus more on full-body movement and hand movement.

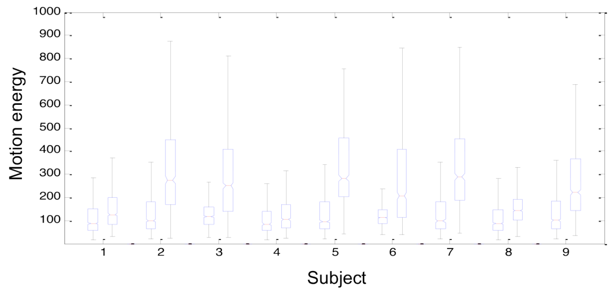

Figure 5 Motion energy comparsion between *Mobile DJ* (right bar) and iPhone counterpart (left bar) of 9 subjects

Figure 5 shows the motion energy of the 9 subjects during the experiment that tested *Mobile DJ* and its iPhone version. The central mark denotes the median energy level, while the edges of the box indicate the 25^{th} and 75^{th} percentiles. It is clear that the subjects’ movements were generally larger when using the *Mobile DJ* device than when they were using the iPhone version. This is consistent with our observations during the experiment. We can therefore conclude that the *Mobile DJ* interface succeeds in motivating a larger body movement.

Table 2 Comparison of user feedback between *Mobile DJ* and iPhone

Features	iPhone	*Mobile DJ*
Functionality	77%	11%
Collaborative Engagement	0%	77%
Portability	44%	44%
Visibility of Actions	22%	66%

Table 2 shows the experiment subjects’ evaluations of the *Mobile DJ* device and its iPhone counterpart. The users were asked to compare *Mobile DJ* with the iPhone on four dimensions: functionality, collaborative engagement, portability and visibility of actions. For each dimension, they were asked to pick the device that they felt was better. They were also given the option of “neither” if they were not able to decide.

From the table, it can be seen that although the users judged that the iPhone’s functionality was better than that of *Mobile DJ*, *Mobile DJ* was judged to be better at providing a collaborative experience. From our interviews with the users, they felt that a mobile application would draw the focus of players to the interaction between the device and the user, rather than to other players. When pressed for their reasons, some subjects suggested that this may be due to the fact that *Mobile DJ* has better error tolerance and offers eye-free control, which removes the need for the users to focus on the device.

Our subjects also felt that the portability of *Mobile DJ* approached that of its iPhone counterpart. There were suggestions that even though the current prototype is large, as it is designed as a wearable interface, it could be potentially embedded into clothes, instead of an external armband. In terms of visibility of actions, nearly all subjects felt that the interface of *Mobile DJ* was intuitive and "fun to control". They also felt that the movement required from the tangible system is closer to the human movement than that required by the iPhone application. Confirming our hypothesis that the tangible interface makes for a better music listening experience, most users reported that the new interface helped them to engaged better into the active listening experience and raised their interest in musical manipulation. Some users also remarked on the need for real-time response with as little delay as possible. Since the larger scale of motion resulted in heightened emotion, they suggested that any delay in the response feedback would result in heightened frustration from the user!

6. EVALUATION

Our previous experiment was designed to test the affordances of the *Mobile DJ* tangible control interface by analyzing the way in which novice users interacted with the system. However, as *Mobile DJ* is very much a musical instrument (albeit an unconventional one), and collaborative musical manipulation or performance requires performers who have established rapport with each other, we felt that a complete set of experiments should involve users who were trained in music, familiar with the system, and were also familiar with each other. Our experiment recruited the previous subjects who had a certain understanding of the *Mobile DJ* interface and musical training.

Our objective is to investigate the way in which our system design supports user interaction, especially in the aspects of collaboration and contextual awareness. Contextual awareness includes the self-awareness of operation, the mutual awareness of the counterpart and the awareness of the performance.

Our experiment subjects were introduced to the *Mobile DJ* system during a ninety-minute session. During the first half-hour, they were asked to explore the interactions and come up with a collaborative, face-to-face performance. Despite them both having musical training, their improvised performance was acceptable neither to themselves nor to the observers.

The second half-hour involved a musical imitation game, in which the experiment subjects were each given a *Mobile DJ* system, and asked to take turns imitating and elaborating upon the special effects introduced into the melody by the previous person. Their initial response was tentative, but they warmed up quickly and were able to perform an enjoyable show.

During the last half hour, the experiment subjects were placed in separate rooms and repeat the previous improvisation and competition tasks.

The experiment was recorded for analysis, and the subjects were interviewed after the experiment. From the analysis and the interview, we obtained the following observations and conclusions:

- *System affordance.* It was reported that the subjects were distracted by trying to remember the different functionalities and operations of the *Mobile DJ* interface during the first half-hour. Their experience improved dramatically in the second half-hour, after they had gotten used to the interface and were able to focus entirely upon the other person and the music. This was an indicator to us of the interface's intuitiveness and affordances in the collaborative experience.
- *Interaction rules and collaboration.* The failure of our experiment subjects to produce an acceptable collaboration in the first half-hour demonstrated that even though both users were musically trained, it was not enough to produce a satisfying collaboration on a new device. This was not unexpected, as it would seem to be the case that it would be difficult for two individuals to be able to improvise a performance within such a short time with a new instrument, and without prior collaborative practice. However, in the second half-hour, the subjects were able to successfully use the system in the game that we set for them, which used a turn-based musical imitation approach, and they reported that they enjoyed the game as well. This indicates the utility of having appropriate interaction rules to guide active listening and collaboration, especially for novice users.
- *Contextual awareness and collaboration.* When the subjects were placed into different physical locations in the last half-hour, we observed that the subjects were able to start their turn almost immediately after the previous turn had ended, similar to the situation when they were situated in the same location. The subjects quickly learned to make use of the ability of the interface to sense signaling gestures such as swinging to indicate "I'm done, here's your turn" to enhance each other's awareness. This suggests that contextual awareness plays an important role for remote musical collaboration, an absence of which highly impacts the overall performance effect. In addition, we also observed much motion synchrony between the experiment subjects. Both subjects tended to move their bodies in response to the beat. Although the way in which they moved their body was different, their movements were synchronized with each other and with the music. This suggests that the subjects were able to immerse into the musical experience.

Figure 6 Face-to-face collaborative performance

7. DISCUSSION

Design principles provide developers with concepts from which to design new types of interactive devices. Based on *Mobile DJ* and its experimental results, we concluded the design problems and suggest recommendation for two aspects: tangible musical interfaces and active collaboration interfaces.

First, wearable devices promote portability. For tangible musical interfaces, sensors could be embedded in clothes to detect the body motion from which different musical effects could be produced. From our experiment, larger scale of motion directly relates to the enjoyment of the experience. This suggests that the design of the interaction should involve as much of the body as possible for these types of interfaces.

We also observed that larger scale of motion increases the frequency of interaction from the user. Therefore, instant feedback and exaggerated effect are suggested as essential factors for the success of tangible musical interfaces. Even short delay time will affect the usability and acceptance of the device.

The location of the device obviously has a significant impact on the active listening experience. The positioning, surprisingly, of sensors, has not been studied extensively. Gemperle [13] states that the criteria for location vary with the accessibility of target user and needs of functionality. However, it also summarized and concluded that eight parts of human body are the most unobtrusive locations for wearable objects: the collar area, rear of upper arm, forearm, ribcage, waist, thigh, shin and top of the foot. The most suitable locations for wearable devices in tangible active music listening, however, needs further investigation.

For the aspect of collaboration, reflecting the user status of other players is an important element. When different users interact over the Internet and are required to collaboratively contribute to the same task, it is obviously crucial for them to know and understand the status of the others in order to provide instant feedback. This feedback, however, does not need to be in the center of the user's attention.

8. CONCLUSION

This paper presents a mobile system, *Mobile DJ*, which uses active music listening and tangible interface to provide users with a social and collaborative music listening experience. Users can apply different styles of musical interaction, such as swinging or sliding, to control the audio track. In addition, it is possible to collaboratively manipulate the music even when the users are in different physical locations. Users can remix, scratch the same sound track or intersperse the melody with specific chords and different instruments. Our experiments showed that the prototype was well received by the users, who enjoyed the tangible interface and the collaborative effort.

The tangible interface of our system is successful at motivating larger body movement when compared to touchscreen mobile devices. In addition, it is possible for experts to use touch exclusively to interact with the system. We also noticed that interaction synchrony can be achieved, even when the users are in different physical locations. *Mobile DJ* therefore provides a tangible and wearable interface for playing active music, and also makes it possible for remote collaborative active music listening.

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