Augmenting the Sound Experience at Music Festivals using Mobile Phones

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ABSTRACT
In this paper we describe experiments carried out at the Nibe music festival in Denmark involving the use of mobile phones to augment the participants' sound experience at the concerts. The experiments involved N=19 test participants that used a mobile phone with a headset playing back sound received over FM from the PA audio mixer system. Based on the location of the participant (distance to the stage) a delay was estimated and introduced to the playback on the mobile phone in order to align the sound in the headset with that from the on-stage speakers. We report our findings from our initial "in-the-wild" experiments augmenting the sound experience at two concerts at this music festival.

ACM Classification Keywords
H.5.1 Multimedia Information Systems: Audio input/output
H.5.5 Sound and Music Computing: Systems

General Terms
Design, Experimentation, Human Factors.

INTRODUCTION
The sound setup at large music festivals and concerts can be quite challenging in terms of providing a good sound experience for all participants present. The sound experience in such large physical areas may involve echo and some sound frequencies, which e.g. could make the quality of the vocal low. In this paper we describe an augmented audio system for mobile phones that aims to improve the overall sound experience at music festivals and concerts. The concept involves a transmitter setup at the PA audio mixer area that transmits the sound via FM directly to a mobile phone. The spectator uses a headset connected to the mobile phone, which provides her with the sound received over FM along the sound from the stage speakers. One of the key challenges in this setup is adjusting the delay of the sound signal received via FM in order to align it with the sound received through the air from the speakers at the stage. In this paper we describe an approach taken to solve this problem, as well as our initial experiences from deploying the setup at two concerts at the Nibe music festival in Denmark.

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RELATED WORK
An early example of enhancing the real world with an audio layer of information is Bederson [1] who experimented with an augmented reality tour guide superimposing audio based on the user location. In another location-based system Mynatt et al. [5] experimented with augmented auditory cues via portable headphones for the purpose of notifying users of nearby activities. However, in terms of music and in a festival setting very little work has been carried out. Two US patents by Clair et al. [2] and Oltman et al. [6] describe systems where a delay is introduced to align audio signals in the context of concerts or music listening. Other augmented reality audio systems include Härmä et al. [3] that describe a system based on binaural microphone elements integrated with stereo ear-phones. The user is exposed to a "pseudoacoustic representation" of the real environment where virtual and microphone signals are combined. A more recent similar augmented reality audio system is described by Tikander et al. [8] and a usability study carried out in different real-life environments concluded that the test participants were willing to use the headset for longer periods of time [7]. Problems reported were mainly related to ergonomics, such as, the headset wire getting stuck and limiting head movement, or wearing the earpieces in situations where it was socially inappropriate. In the mobile domain augmented reality has gotten more attention recently, as modern smart phones have become capable platforms for augmented reality applications. However, focus has primarily been on visually oriented applications typically overlaying the displayed image from the camera viewfinder with relevant location-based information.

AUGMENTED SOUND SYSTEM
The architecture of our augmented sound system is depicted in Figure 1. The audio stream is split in the audio mixer and goes to both stage speakers and an FM transmitter. The mobile phone receives the stream from the FM transmitter. Based on received GPS coordinates a distance is calculated and hence a delay for the FM stream is calculated. The

audio from the FM receiver is then played back to the user aligned with the sound from the speakers. There are several delays present in the system of which some can be considered constant in a given setup (e.g. the delay between the mixer, speakers, and FM transmitter and the delay introduced by the mobile phone) whereas the delay in the air depends on location and needs to be calculated regularly in order to ensure an undisrupted listening experience. In the implemented prototype, we used a simple approach to the delay estimation, based on GPS-based measurements of the distance of the user to the stage speakers.

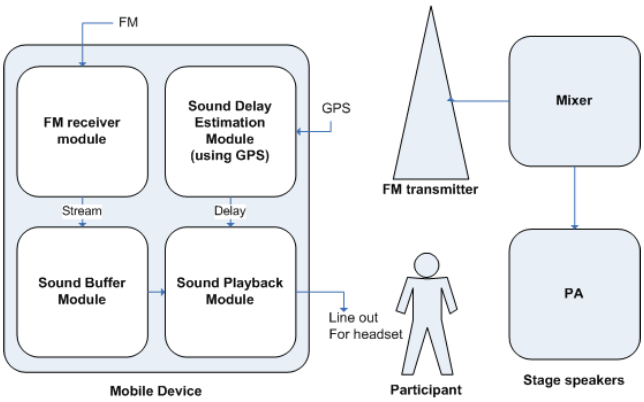

Figure 1. Overview of the augmented sound system

A prototype mobile application was developed for the Maemo platform and deployed on Nokia N900 mobile phones. The key feature of the application was to deliver the delayed sound stream from the FM receiver to a connected headset. It also performed the automated estimation of the delay of the FM stream, based on the received GPS coordinates. The mobile application consisted of modules for the graphical user interface, delay logic, FM receiving, sound buffer, and playback module (see Figure 1). The delay module communicated via the DBus interface to the FM controller with instructions to set the delay. This was based either on the automated calculation in the sound delay module or user adjustment in the user interface. The raw audio was captured from the FM chip, recorded in a buffer, delayed in the queue and played back to the headphones.

In the present prototype a simple method for estimating the delay of the audio stream from the FM receiver was implemented using the position of the mobile phone in relation to the stage. Experimentally we found the fixed delay introduced by the specific mobile phone hardware and software (Nokia N900). This was used in calculating the FM audio stream delay based on the mobile phone distance to the stage expressed as

$$\boldsymbol{\Delta} = \frac{\boldsymbol{d}}{\boldsymbol{v}} - \boldsymbol{\delta}$$

where $\boldsymbol{\Delta}$ is the total delay introduced [sec], $\boldsymbol{d}$ is the distance of the phone from the stage [m], $\boldsymbol{v}$ is the speed of sound in the air (assuming 343 m/s at 20 degrees Celsius), and $\boldsymbol{\delta}$ is the delay introduced by the hardware and software on the mobile phone (230 ms). The Haversine formula was used for distance calculation from two GPS coordinates, with an error margin below 1%, which is sufficient for our purpose.

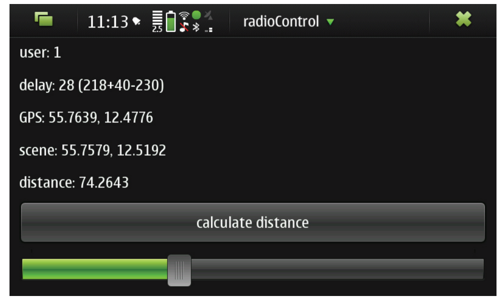

Figure 2. Screenshot of the mobile application user interface

The user interface of the mobile application is shown in Figure 2. It includes a user id (for data analysis purposes), a calculated delay in milliseconds, consisting of the distance estimated delay (218 ms), manual adjustment (40 ms) minus the fixed device delay (230 ms). In addition it shows the current GPS coordinates, the fixed stage GPS coordinates, a calculated distance from the stage. The user can interact pressing the "calculate distance" button to force distance (delay) recalculation or use the slider to manually adjust the delay in 10 ms steps. The volume is adjusted on the headset or mobile phone.

METHODOLOGY AND EXPERIMENTS

We carried out a set of initial tests of our mobile application prototype with FM receiving on a football field (roughly 100 meters long) at our university campus. The setup involved a radio, an amplifier, and two speakers that were situated at the end of the field. We tuned to the same radio station on the mobile phone and took measurements at different distances to do sound recordings and estimate the sound delay. Based on these experiments we found that the delay introduced by the receiver in the mobile phone was about 230 ms corresponding to a distance of 70–80 meters from the speakers.

The in-the-wild evaluation of the prototype system, including our mobile application and broadcast equipment, was then carried out during two concerts at the Nibe festival in Denmark. The aim was to evaluate the concept and prototype. Festival participants were chosen randomly for the evaluation of the system right before and during the concerts. The participants were given a brief oral explanation about the concept and the mobile application before they were provided with a mobile phone. They were encouraged to experiment with the application, adjustments, and their distance to the stage, as well as listening both with and without the headset. After testing the application, participants were asked to fill out a questionnaire to assess their experience. Before the experiment were initiated at the Nibe festival we calibrated the application on the mobile device with the GPS coordinates of the center of the stage, at point (a) in Figure 3. The FM transmitter in the mixer area (b) was switched on for pilot testing and the signal was tested on the mobile phone at different distances. A good position was found at the very end of the concert area (c), where the distance was sufficient for the system to work (above 70 meters) and the crowd was less dense, allowing interaction with the test participants.

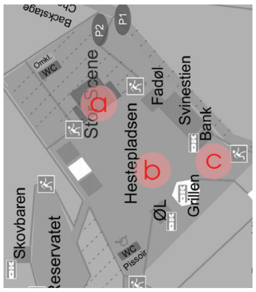

Figure 3. Overview of the Nibe festival concert area. a) The stage where the speakers were located, b) The mixer area with the FM transmitter, and c) Approximate participant location

The experiments with participants were carried out during two concerts in the same evening. The first concert was by *Selvmord*, a Danish hip-hop group, the second by *Nephew*, a Danish pop-rock band. During those two concerts, representing different music genres, 10 and 9 participants respectively tested and evaluated the system. The participants were chosen in groups of 3–4 people, asked to be located around the area (c). They were handed a mobile phone (Nokia N900) with the application running and delay estimated based on their position. They spent on average about 10 minutes testing the application, changing their position (moving towards and away from the stage) and with the headphones on and off to compare the difference between regular and augmented sound. Afterwards the participants filled out an anonymous questionnaire. Between the two concerts adjustments in the equalizer on the FM transmitter were made enhancing higher frequencies in the audio.

RESULTS

The study included 19 participants (15 male, 4 female), and were limited by the four mobile phones available to us. An overview of the results from the questionnaires can be seen in Table 1 (C_{all}), with 10 participants from the first concert (C_1) and 9 participants from the second concert (C_2).

The first 3 questions (q_1–q_3) concern the overall user experience, and from the answers we find an overall positive assessment of the system. The next two questions (q_4–q_5) relate to the delay as perceived by the participants. Even with the semi-automatic distance-based delay estimation the sound experience is assessed positively. Questions (q_6–q_7) assess the mobile application prototype (user interface) neutrally, which is satisfactory for this early prototype. The last two questions (q_8–q_9) concern the comfort of using the augmented sound system. We see that the headset did not really bother the participants (q_8) and it can also be seen that generally they did not have an experience of being isolated (q_9). The average participant age is shown in q_{10}.

Question	C_1	C_2	C_{all}	SD
q_1 How was the effect on your experience of the concert?	4.3	3.8	4.1	0.85
q_2 How was the overall sound experience?	4.1	4.0	4.1	0.62
q_3 Was there a big difference in sound experience with and without headset?	4.1	3.8	3.9	0.76
q_4 Were the two sound signals aligned?	3.6	3.1	3.4	0.87
q_5 Did you experience sound distortion or delay during the concert?	2.5	2.1	2.4	1.13
(5) very positive (4) positive (3) neutral (2) negative (1) very negative				
q_6 How were the options for adjusting the sound on the mobile phone?	3.2	3.0	3.1	0.99
q_7 What was your general impression of the user interface on the mobile phone?	3.2	3.5	3.3	0.92
(5) very good (4) good (3) average (2) below average (1) bad				
q_8 How did you feel wearing the headset during the concert?	3.4	3.2	3.3	1.26
(5) comfortable (4) fine (3) neutral (2) slightly annoying (1) uncomfortable				
q_9 Did you feel isolated during the concert due to the headset sound?	2.6	2.0	2.4	1.32
(5) very much (4) some (3) average (2) below average (1) no				
q_{10} Age (years)	25.6	38.5	30.4	13.6

Table 1. Average results of the questionnaires from the two concerts (C_1,C_2) and overall (C_{all}) with standard deviation (SD)

In the open part of the questionnaires several participants reported the sound experience as "clean" and that it was easier to hear the vocal and guitars. As mentioned we adjusted the general equalization at the mixer between concerts, but then a few participants reported "a lack of bass" during concert 2. The mobile user interface received a neutral assessment, but a few suggested adding features for adjusting the equalization of the sound and automatic calibration of the delay. Several made a note that the headset sound would stop temporarily when pressing the button for recalibration. A couple of participants had concerns about the headset, saying that the choice of the model was important and one suggested using a different headset. In the field for additional comments in the questionnaire participants gave promising feedback including "really nice experience", "nice idea" and "exciting project". However, one participant reported that "the social aspect of a concert is lost".

DISCUSSION

We have gained interesting initial insights on the utility of augmenting the concert sound experience in a festival setting from the "in-the-wild" experiments. The responses from the test participants were generally positive as shown in the results in Table 1. It turned out to be quite challenging to carry out the experiments in the very crowded environment characterized by loud music and limited light, especially when people had to fill out the questionnaires after trying the mobile application. As the inaccuracy of the GPS typically produced an audible delay, manual fine tuning of the delay to align the sound signals was needed. The slider in the user interface shown in Figure 2 was used for this purpose. Some test participants had no problem telling how to adjust the delay, whereas a few had huge trouble figuring out how to align the two sound signals. A few test participants reported that the 10 ms steps in the slider alignment was too long to get a satisfying calibration of the system.

A key issue was the level of isolation as experienced by the test participants, as one of the main reasons for these activities is socializing. Bederson [1] discusses the issue of augmented audio systems introducing a feeling of isolation of the participants, as the social purposes are potentially obstructed. One participant reported this as being a potential problem and something that could ultimately make him/her abandon the solution. The majority of participants were positive as they appeared to value the overall improved sound experience and were not too concerned with the feeling of isolation (see Table 1). However, the short duration of use must be taken into account here. Part of the issue can be addressed by improving the mobile application, such as easy muting of the sound in the headset, as also proposed by Mueller and Karau [4]. Overall we would argue that our system enable augmenting the sound experience while preserving an experience involving multiple modalities in the festival environment. Participants can still hear the sound from the speakers, feel the bass in their body, being outside feeling the temperature and air pressure, as well as getting the visual experience (stage show and lights). Moreover there is still the social aspect of being with people including friends and other participants making it a common social experience. We noticed that especially a handful of teenagers that tested the prototype were very positive. One of them phrased it in the questionnaire (translation from Danish) "It's almost like listening to a CD". Although we would not describe the sound as CD quality it still underlines the proof-of-concept of the system, as the enhancement of sound frequencies resulted in participants reporting an improved sound experience involving clearer vocal and guitars.

FUTURE WORK

Future work could include alternative ways to automatically calibrate the system according to the position of the test participants and potentially avoid the manual calibration in the present system. An automatic approach could involve using the embedded microphone and the FM receiver to align the signals based on analysis of the sound signals. This could also include utilizing additional cues available from the embedded mobile phone sensors (compass and accelerometer) to allow 3D sound positioning based on the participant position. A concern in the present prototype was the fixed delay introduced by the hardware and software components in the mobile phone, meaning that participants could not go closer to the stage than approximately 70 meters. Future studies could explore different hardware and software with a smaller delay. Moreover the experiments could involve different configurations of the setup, as well as testing different types of headsets. Also studies with a larger sample size and over longer duration, such as the entire concert would be relevant. Further development of the mobile application could include an equalizer allowing for optimization of the sound experience according to individual preferences. For the purpose of easier interaction with people in proximity and to avoid the feeling of isolation, a simple switch for easy muting of the headset sound could also be relevant. Exploring other use cases such as the artistic potential of this technology would be interesting.

CONCLUSIONS

Our studies have shown that the participants were generally positive towards the augmented sound solution, and participants reported an improvement of the sound experience during their short term use of it. As expected concerns were raised that wearing the equipment during a concert would lead to a feeling of isolation. However, the trade-off between a better overall sound experience and the feeling of isolation might be partly dealt with by introducing muting or communication features into the mobile application. Our studies have provided useful initial insights into the application of augmented sound technologies in a concert setting and it calls for further studies as well as methods for delay calculation to automatically align the sounds signals.

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