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Advertisement Distribution Systems using Acoustic Data Transmissions

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Abstract : In this paper, we develop the advertisement distribution system using acoustic data transmission. While playing the advertisement on the television, additional data such as the company's phone number or the URL of the company is modulated and sent via the audio signal simultaneously. The speaker of the Android-operated smartphone receives the encoded audio signal, processes and decodes the transmitted data. If the data is obtained correctly, the smartphone will show a pop-up screen which, upon pressing, will redirect a user to call the company or to the URL of the company's website. The receiver algorithm is implemented in the application in the smartphone which is run in the background. This application is promising for advertisers who want to broadcast additional information from advertisement presented in the television, radio or digital signage. From the experiment, the bit-error ratio (BER) is approximately 10^{-2} when the distance between the transmitter and the receiver is less than or equal to 5 meters. The application shows a pop-up menu corresponding to the encoded information with at least 80% accuracy. The algorithm used in this paper can be applied in digital watermarking in different media such as video, software and network for other purposes like security. Future works will focus on improving the transmission performance through forward error correction code while maintaining low sound quality degradation.
Keywords: Acoustics Data Transmission, Modulated Complex Lapped Transform (MCLT), Spread sequence, Synchronization.

1. INTRODUCTION

Mobile advertisement revenue has shown significant growth during the past couple of years. Data from [12] shows that mobile advertising revenue soared 66% to 20.7bn in 2015 from 12.5bn in 2014. One of the main reasons that contributes to this huge rise is due to the proliferation of affordable smartphones around the world and almost complete coverage of wireless network infrastructures (WiFi, 3G or 4G network). Examples of mobile advertisement include SMS advertisement, mobile web browser advertisement and advertisement in mobile apps [13]. By displaying the advertisement of products or services on the users' smartphone screens, interested users can simply click the ads to look for more information about them or even making a purchase. In addition, advertisers can track the purchase records of these users and recommend other related products or services to them.

Despite its promising approach, some advertisers still prefer traditional off-line advertisement where information about the products or services are presented on papers, name cards, billboards, televisions or digital signage. Study show that carefully crafted off-line advertisement exhibits stronger brand impression to target customers and can capture users' attention at higher rate compared to the online ones. However, the cost of the advertisement is much higher compared to the online ones and it's very difficult to measure the users' responses for each advertisement.

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Based on the pros and cons of both online and offline advertisements, many companies advertise their products or services by combining both approaches. This can be done using a business card which includes a QR code linking to a company's website or attaching a URL or phone number of the companies on the advertisements presented on the billboards, televisions or digital signage. Fig 1 shows an example of the advertisement of a car insurance company called DirectAsia.com presented on the television [11]. By showing this advertisement on some televisions or digital signage, interested customers can look for more information by keying the posted URL or phone number into their smartphones to get more information about this product or service.

Figure 1: An example of a car insurance advertisement exhibited on the television [11]. The additional information of the advertisement such as the phone number and the company's URL is presented by the end of the advertisement and lasted only a couple of seconds. Interested people who want to look for more information are required to memorize the URL or phone number and key them in the smart phone later to access more information about the car insurance company

However, delivering the URL or phone number to the smartphone could be very inconvenient in many aspects. People may forget the exact phone number or URL of the website. To avoid this problem, they may need a pen or pencil and a piece of paper to write down this information and later key in that information into the smartphone. Taking a picture of this information is very inconvenient since people still have to switch between pictures and the web browser to key-in the URL. Due to limited air time or other unknown issues, that information may be presented only a couple of seconds before it disappear. This becomes very difficult for interested people to memorize or write down those information in time. Advertisers circumvent this problem by using short URLs or keywords but it's still inconvenient for people to deliver information presented on the traditional offline media such as television or digital signage into the smartphones.

To overcome this problem, a number of approaches have been investigated to solve this issue. One approach is to let the WiFi or cellular network infrastructure broadcasts that additional information simultaneously while the advertisements are broadcast on the television or radio. In this way, when people see the advertisements on the television or hear the advertisements on the radio, they can use their smart phone to access the additional information such as the company's URL on their smart phone via the WiFi or cellular network infrastructure. However, broadcasting the additional information on WiFi or cellular networks while the advertisements are broadcast on the television simultaneously is very difficult. The advertisers need to coordinate both types of information so that they are broadcast simultaneously. This becomes impractical since the advertisers normally do not have accesses to local WiFi networks.

Another approach to solve this problem is to encode the additional information in the audio file which is normally played together with the pictures when broadcasting that advertisement on the television. One approach is to modulate the additional information using amplitude shift keying (ASK) or frequency shift keying (FSK) [2],[8] schemes. Using this approach can achieve high data rate transmission at the expense of poor sound quality. Another method is to use audio watermarking techniques [4] to encode additional information. Despite its robustness to distortions due to signal processing, the data rate is too low to transmit meaningful additional information within a couple of seconds of the advertisement. Due to its widespread use in data communications, orthogonal frequency division multiplexing (OFDM) [3],[5] is another alternative that can be used to encode information and send it over the acoustic signal. However, serious audio degradation occurs due to blocking artifacts and this inhibits its use in real environment. Recently, another type of signal transformation called modulated complex lapped transform (MCLT) [1],[6],[7],[9] is proposed to encode data and transmit it over the acoustic signal. MCLT produces better sound quality compared to using OFDM since it is derived from 2 x oversampled Discrete Fourier Transform (DFT) and does not possess blocking artifact.

In this paper, we focus on delivering the additional information from the television or digital signage to the smartphone using audio signal. Inspired by the success of MCLT to encode data over the acoustic signal with low sound quality degradation, we propose the advertisement distribution system using MCLT modulated acoustic data transmission. Additional data such as the company's telephone number or the URL of the company is modulated by modifying the phase of the MCLT coefficients of the sound. After modulation, the audio and pictures of the advertisement are stored in mp4 format. While playing the advertisement on the television, additional information is broadcast via the audio simultaneously. Due to its popularity, we use the Android-operated smartphone as our receiver. The speaker on the Android-operated smartphone receives the audio. Then, it processes the audio input and decode the transmitted data. If the data is decoded correctly, the smartphone will show a pop-up screen which, upon pressing the button, will redirect a user to the URL of the company's website. The overall receiver algorithm is implemented in the process operated in the smartphone which is run in the background. From the experiments, the BER is approximately 10^{-2} across the distance of interest.

The transmitter and receiver algorithms are discussed in Section II. Section III discusses the experiments and results. Section IV concludes the experiment.

2. METHODOLOGY

In this section, we describe acoustic data encoding and decoding processes of the data transmission system.

A. Acoustic Data Encoding

Fig 2 exhibits a block diagram of the transmitter. This process is processed off-line to generate the output file in mp4 format. First, each data bit $d_k \in 0, 1\}$ where $k \in [0, K–1]$ is repeated Q times at Bit Repetition block to fit data into the transmission frame and improve reliability. K is the size of the data fitted within a frame. Then, the output data bits from B data blocks ($c_b[r] = [c_{0,b}[r], c_{1,b}[r],..,c_{N-1,b}[r]]$, $b \in [0, B–1]$) are combined with the synchronization block $p = [p_0, p_1,.., p_{N-1}]$ at Frame MUX block to formulate the r^{th} transmit frame as shown in Fig 2. $r \in [0, R–1]$ where R is the total number of transmitted frame. B is the number of data blocks per frame and N is the transmitted blocksize. The synchronization sequence ($p_n \in \{0, 1\}$ where $n \in [0, N–1]$) is a random binary sequence which will be used by the receiver to identify the start of the frame. Fig 3 shows the structure of the r^{th} transmitted frame which begins with one synchronization block followed by B data blocks and can be written as $[p, c_0[r], c_1[r],\ldots,c_{B-1}[r]]$. Each frame will be mapped into the spread spectrum sequence before modulating with the audio signal. This mapping scheme spreads data across multiple frequency bands to improve transmission reliability. In addition, by spreading data over multiple bands, we can transmit each data symbol with low power to mitigate the impact of data symbol on sound quality. For simplicity, we use the spread sequence whose length is equal to 4 [1]. The mapping from information bit (both data and synchronization sequence) to spread sequence is implemented as follows. Given the nth data or synchronization bit $c_n (p_n) \in \{0, 1\}$, the spread sequence (s_n) corresponding to $c_n (p_n)$ is:

$$\begin{aligned} c_n(p_n) &= 0, \\ s_n &= \{0, 1, 0, 1\} \\ c_n(p_n) &= 1, \\ s_n &= \{1, 0, 1, 0\}. \end{aligned} \quad (1)$$

The output spread sequence will be encoded into the audio file which will be explained in the next paragraph.

The output spread sequence will be encoded into the audio signal by modifying the phase of the audio files represented in MCLT domain. First, we convert the audio file (preferably in .wav format) into the MCLT format. MCLT is a 2 x oversampled generalized DFT filter bank. Converting audio signal into MCLT coefficient is known to cause fewer artifacts than standard DFT when processing the audio files. MCLT processes a 2L real-valued vector of audio samples into an L complex-valued vector of MCLT coefficients. We choose only M out of L frequency bands to encode the data to limit the impact of data encoding on the sound quality. To limit the amount of interferences across neighbor blocks of MCLT and neighbor frequency bands, we encode data over every other blocks and frequency bands as discussed in [6].

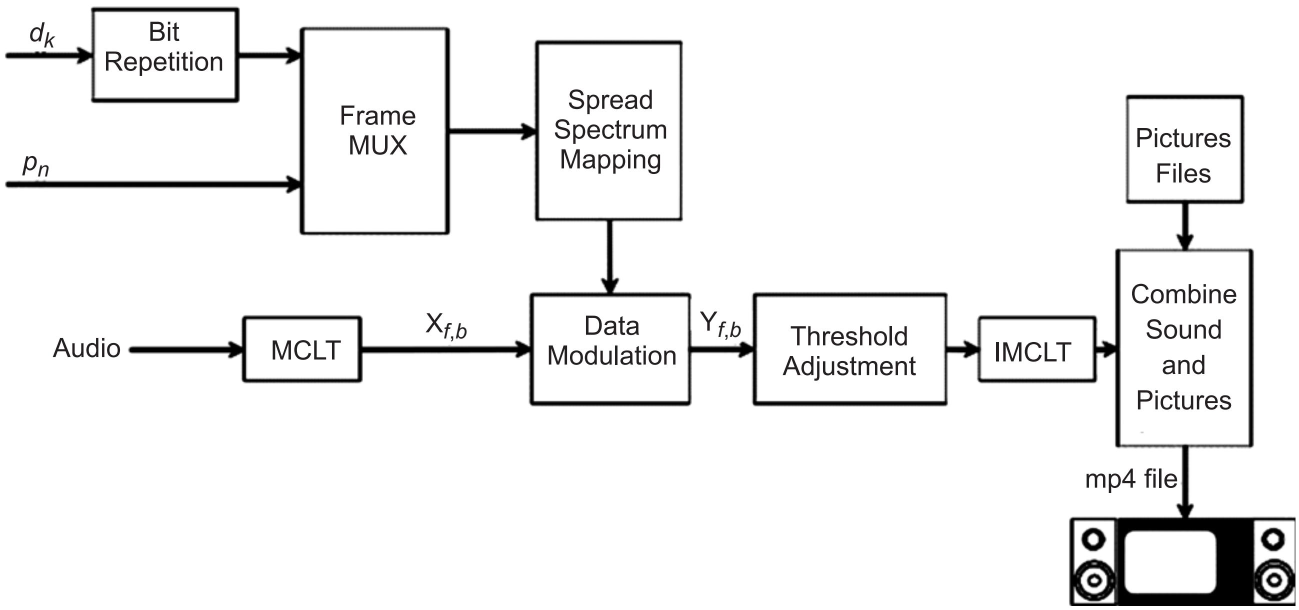

Figure 2: Block diagram of the transmitter. Data (d_k) is repeated and multiplexed with the synchronization sequence (p_n). They are expanded across multiple frequency bands using the spread spectrum sequence. The output sequence is modulated into the MCLT coefficients of the audio signal using BPSK modulation scheme. The output audio is combined with picture files to generate a movie file in mp4 format.

After we convert the audio file into MCLT format, we encode the frame of data and synchronization sequence into the audio file by modifying the phase of the MCLT coefficients corresponding to the frequency bands that we intend to encode the data. We use Binary Phase Shift Keying (BPSK) modulation where the corresponding modulated phase of the MCLT coefficients is either 0 or π when the input bit is 0 or 1, respectively. The MCLT coefficient of the encoded data ($Y_{f,b}$) can be written as

$$Y_{f,b} = |X_{f,b}| \exp(j s_k \pi) \quad (2)$$

where $X_{f,b}$ is the MCLT coefficient at the f^{th} frequency and b^{th} MCLT block and $s_k \in \{0,1\}$ is the encoded spread sequence. After data modulation, we need to adjust the magnitude of the MCLT coefficient whose phase is modulated with the data. The magnitude of $Y_{f,b}$ cannot be too small otherwise the receiver cannot detect the encoded bit due to noise existed in the environment. Therefore, after encoding, the magnitude of $Y_{f,b}$ that are less than a threshold (Th) will be adjusted to be equal to Th. The threshold value is obtained empirically based on subjective sound quality assessment and will be discussed more in the next section. This magnitude adjustment process is implemented in the Threshold Adjustment block as shown in Fig 2. Then, a whole frame of the adjusted MCLT coefficients are converted into time domain using IMCLT

(Inverse MCLT) process. After that, the encoded audio samples will be combined with the picture files to create a movie file in mp4 format that will be played in a television monitor screen. The encoded audio samples will be sent out on the speakers corresponding to the images presented on the TV screen as shown in Fig 2.

Figure 3: A transmit frame consists of 1 synchronization block followed by B data blocks. The receiver uses the synchronization block to identify the start of the frame before decoding the remaining data blocks.

B. Acoustic Data Decoding

Fig 4 illustrates a block diagram of the receiver which is operated in the smart phone. This process is implemented in real-time. In particular, the receiver extracts the data embedded in the incoming audio, processes and exhibits them on the user's smartphone screen. When the receiver receives a sample of the audio signal via the microphone, to be able to find the beginning of the data frame, the receiver must detect the synchronization block inserted at the beginning of every frame. Assume that $r = [r[0], r[1],\ldots, r[8L-1]]$ is the received audio samples in time domain. They are transformed into MCLT coefficients. Let $R_f[q] = [R_0[q], R_1[q],\ldots, R_{L-1}[q]]^T$ is the column vector of MCLT coefficients where $R_f[q] = \text{MCLT}\{[r[q], r[q+1],\ldots, r[q+2L-1]]^T\}$ and $q \in [0, 2L-1]$. MCLT$\{c\}$ is a function that transforms a column vector c of size 2L – 1 into a column vector of MCLT coefficients of size L [9]. Then, for each $R_f[q]$, we calculate the cross-correlation function between $R_f[q]$ and a spread sequence of the synchronization sequence (p). The cross-correlation output ($cr(q)$) can be written as

$$cr(q) = \sum_{f=0}^{L-1} R_f[q]Ps[f] \tag{3}$$

where $Ps[f]$ ($f \in [0, L-1]$) is the spread sequence of the synchronization sequence. The frame starting point is calculated as follows,

$$\hat{q} = \arg\max_{q\in[0,8L-1]} cr[q]. \tag{4}$$

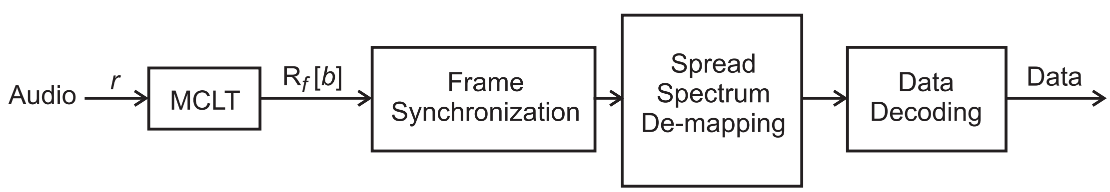

Figure 4: Block diagram of the receiver which is implemented in the Android-operated smartphone. The smartphone uses a microphone to receive the encoded audio and process it to obtain the embedded information. Then, the smartphone will display the pop-up menu corresponding to that information on the smartphone's screen.

The synchronization process is done in the Frame Synchronization block as presented in Fig 4. After the frame starting point is located, the receiver moves to the starting point of each data block within a frame and calculate MCLT of that data block. The phase of the MCLT coefficients of the encoded frequency index and frame are extracted to calculate the data. Finally, the smartphone processes the data and presents the output on the screen of the smart phone.

3. EXPERIMENTS AND DISCUSSIONS

A. Experiments

The implementation parameters are listed in Table I. We use two movie clips recorded in .mp4 format to test our advertisement distribution system. The first clip (Clip1) is the advertisement of Lamborghini [10] and the second clip (Clip2) is the advertisement of car insurance company named Direct Asia [11]. The main difference between both clips is that the sound in Clip2 mostly contains human speech while

Clip1 mostly consists of car engine sound. The main reason for selecting both clips is to see the impact of acoustic data encoding on the sound quality which will be measured using MUSHAR test [8].

Table 1

Experimental Parameters

Sampling Frequency	*44100 Hz*
MCLT Block Size (2L)	2048 samples
Number of bit repetitions (Q)	4
The transmitted blocksize (N)	23
A number of data blocks within a frame (B)	3
Information blocksize per frame (K)	69
Data Encoding Frequency	6-10 kHz
A number of MCLT coefficients to be encoded (M)	92
Modulation Scheme	BPSK
Frame Duration	0.2 second
Average data rate	86 bps
Movie output format	Mp4
Minimum Data Encoding Magnitude Threshold	10 dB lower than the maximum sound magnitude (Th = –10dB)
Encoded sound loudness (Speaker1)	80dB measured at 1 meter
Background noise loudness (Speaker2)	40dB (Scenario 1) and 60dB (Scenario 2) measured at 1 meter

From Table 1, we modulate data into the sound of the movie clip using MCLT whose block size is equal to 2048. A transmit frame consists of 1 block of synchronization sequence followed by 3 blocks of data. The synchronization sequence is a pseudo random sequence known at the receiver. After encoding, the magnitude of the MCLT coefficients whose phases contain data is adjusted to be at least 10 dB lower than the maximum sound magnitude (Th = –10dB). These values are obtained empirically through subjective quality test over a number of test subjects. The encoded sound will be combined with pictures to produce a movie file in mp4 format. We play this movie file over an LCD TV with 1 speaker in the lab space.

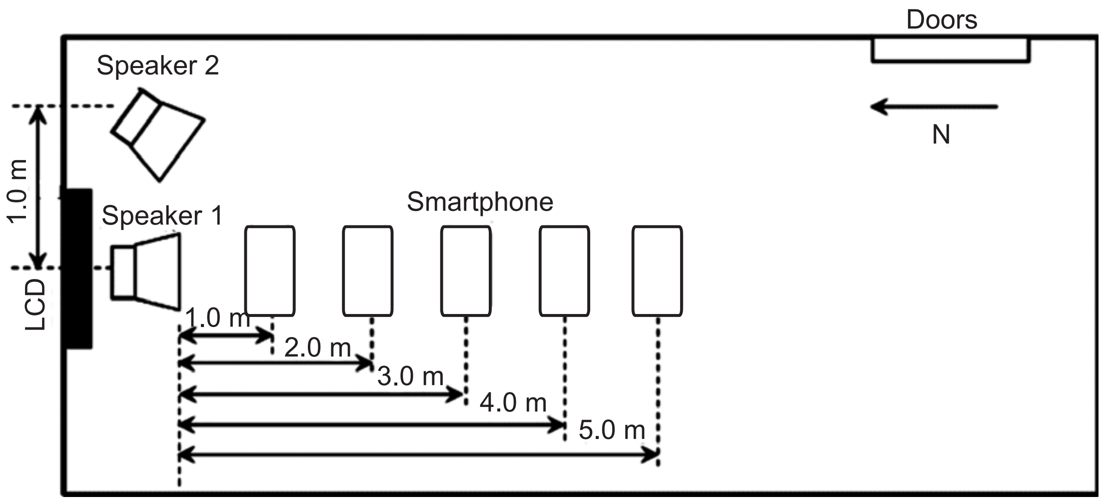

Figure 5: Lab space used for performance evaluation. The lab is 18.8 meter in width and 26.90 m. in length (not scale). Height of the lab space is 3 m. Speaker 1 emits the encoded sound whose loudness is 80 dB at 1 meter from the speaker. Speaker 2 emits noise whose loudness is 60 dB at 1 meter.

We evaluate the performance our advertisement distribution system in terms of the quality of encoded sound, transmission performance and the accuracy of the application to present the pop-up screen.

B. Subjective Quality Test

We conducted subjective quality test to evaluate the sound quality of the sound encoded with data. We use MUSHRA test over 10 test subjects with 5 male and 5 female. Test subjects age between 22 and 61 years old. All test subjects have normal acoustical acuity. Each advertisement sound is encoded into 3 separated files. The first one does not have any data encoded. The second one has data encoded where the minimum data encoding threshold is set to 10 dB lower than the maximum sound magnitude (Th = –10dB). The third sound has data encoded whose encoding threshold is set to 13dB lower than the maximum sound magnitude (Th = –13dB). Since our experiment use only Clip1 and Clip2 advertisements, each test subject has to listen to 6 sound in total. During the subjective sound quality assessment, each sound is randomly played for each test subject. After each play is done, the test subject filled in the score. Then, a new sound is played and this process is continue until all 6 sound have been played.

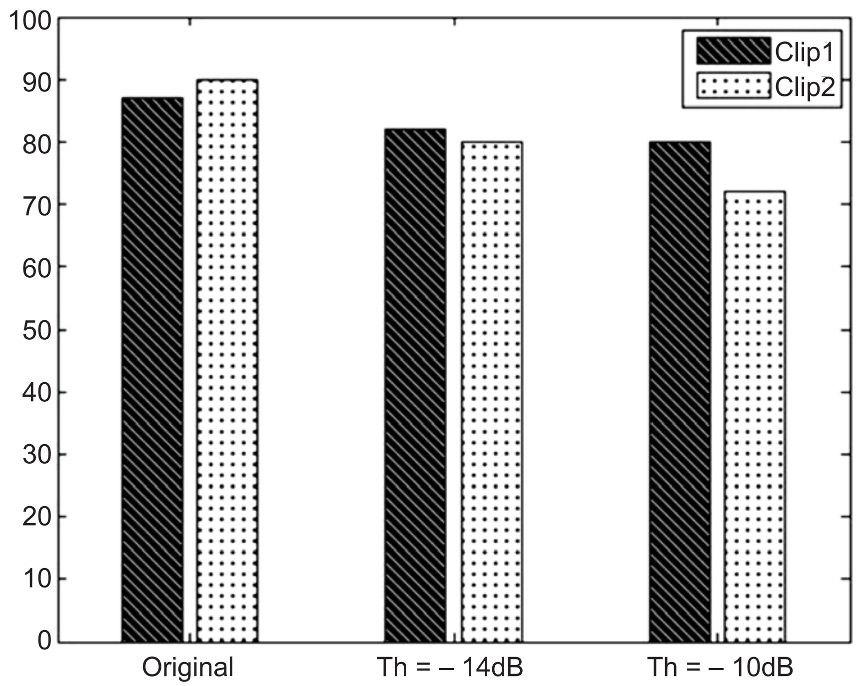

Figure 6: MUSHRA test score

From Fig 6, as expected, as the threshold is higher, the average sound quality is less. Also, sound from Clip2 exhibits worse sound quality than that of Clip1. Since the sound from Clip2 consists mainly of speech, the impact of encoded data is more noticeable compared to that of Clip1 whose sound is mainly consists of car engine sound. However, we believe that perceive ability of noise due to data encoding in the sound should be less in real environments where people barely focus on sound quality of the advertisements. Also, different types of noise (people voice, music) are presented in real environments and this should help obscure noise from data encoding. Therefore, even though its MUSHRA score is lower, we choose the minimum magnitude threshold at –10 dB (Th = –10dB).

C. Transmission Performance

We test the performance of the transmission system in term of the bit-error-ratio (BER). The experiment is conducted at the lab space as shown in Fig 5. Data bits are randomly generated and modulated with the sound from Clip1 to generate a movie file. The file is played on the LCD monitor and its sound is emitted from Speaker 1. The receiver is an Android-operated ASUS Zenfone4 smartphone running the application implementing the receiver algorithm as discussed in the previous section. During the test, the smartphone also ran other typical applications (WiFi, Bluetooth and GPS). The receiver is 1, 2, 3, 4 and 5 meters away from the speaker. We test our system in the lab space under 2 scenarios. In the first scenario, the background noise in the room is mainly from air-conditioner whose loudness is approximately 40 dB. In the second scenario, we generate an artificial background noise emitted from Speaker 2 whose loudness is approximately 60 dB measured at 1 meter. In both scenarios, the loudness of the speakers that emit the encoded sound (Speaker 1) is 80dB measured at 1 meter from the speaker. Also, the transmitter and receiver are within line-of-sight with each other.

Fig 7 shows the BER performance of the transmission system when background noise level is equal to 60dB and 40dB. The threshold is set to -10 dB and the distance of interest is from 1 meter to 5 meter. Each result is plotted together with its 90% confidence interval. From the figure, we can see that the BER is higher as the distance between the transmitter and receiver is longer. On average the BER is approximately 10^{-2} across the distance of interest.

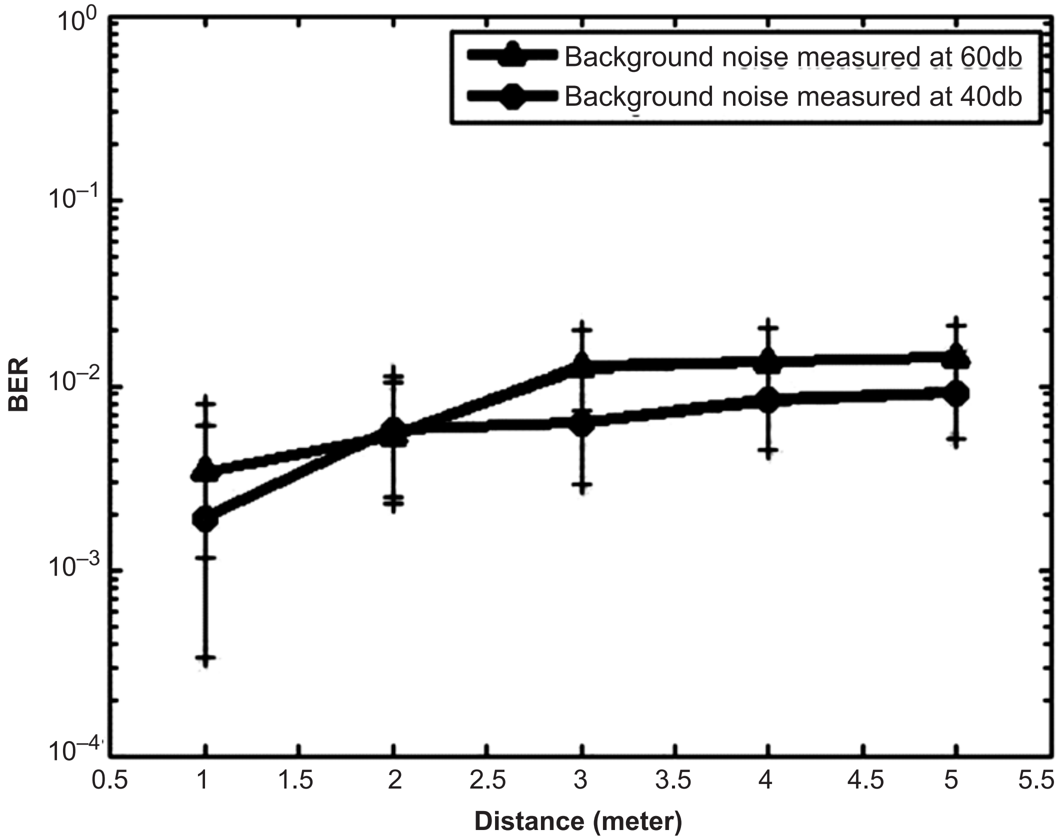

Figure 7: BER performance of transmission system

D. Receiver Accuracy to Present Advertisement Information

We test the performance of the transmission system in term of the accuracy of the receiver to present the advertisement information. Test subject has to turn on the application to record the sound. After that, the smartphone processes the recorded sound by decoding the bit sequence encoded in the sound. Then, the application will compare the decoded sequence with those stored in the smartphone database. If no sequence matched is found, the application will discard the recorded sound and check the next one. If the application finds the matched sequence with those stored in its database, it will fetch the URL corresponding to that bit sequence and show the pop-up menu in the test subject's smartphone. If the test subject wants to look for more information about the advertisement, then the test subject simply clicks that link and the application will show the information the advertisers want to provide. Fig 8 shows the pop-up menu in the test subject's smartphone corresponding to Clip1 advertisement and the following URL page after the test subject clicked the URL 🔗 link.

In this experiment, 2 types of bit sequence embedded in the sound corresponding to Clip1 and Clip2 are encoded and transmitted while playing the movie file. Each movie clip is played for 10 rounds. In each round, when the movie clip starts, the user turns on the application (run in background) to record the sound and holds the smartphone in the test subject's hand. While holding the smartphone and watching the clip presented on the monitor, if the smartphone shows a pop-up menu corresponding to the advertisement presented on the screen, the test subject then clicks the link to confirm that correct information is received. If nothing is showed up or the menu that shows up does not match the advertisement presented in the monitor, then the test subject marks this test as incorrect.

Table 2 and 3 show the receiver accuracy to present advertisement information when the background noise is 40 dB and 60 dB, respectively. From the tables, the accuracy is at least 80% for both movie clips. No significant performance difference is discovered from these results.

Table 2

Accuracy of the data transmission system when threshold = -10DB when background noise is 40 dB

Distance (meter)	*Accuracy when playing Clip1*	*Accuracy when playing Clip2*
1.	80%	100%
2.	100%	90%
3.	90%	90%

Table 3

Accuracy of the data transmission system when threshold = –10DB when background noise is 60 dB

Distance (meter)	*Accuracy when playing Clip1*	*Accuracy when playing Clip2*
1.	80%	90%
2.	90%	80%
3.	90%	90%

Figure 8: Examples of pop-up screen showed up after the application successfully decode the data encoded in the sound from Clip1. Once the test subject clicks , the smart phone will redirect the user to the webpage *http://www.lamborghini.com/en/models/huracan-lp-610-4-avio/overview/* as shown in the picture on the right hand side.

4. CONCLUSIONS

We develop the advertisement distribution system using acoustic data transmission. While playing the advertisement on the television, additional data such as the company's telephone number or the URL of the company is modulated and sent via the audio signal simultaneously. We use the Android-operated smartphone as our receiver. The speaker of the smartphone receives the encoded audio signal, processes and decodes the transmitted data. If the data is obtained correctly, the smartphone will show a pop-up screen which, upon pressing, will redirect a user to call the company or to the URL of the company's website. This application is promising for advertisers who want to broadcast additional information from advertisement presented in the television, radio or digital signage. From the experiment, the BER is approximately 10^{-2} across the distance of interests. The application shows a pop-up menu corresponding to the encoded information with at least 80% accuracy. Future works will focus on improving the transmission performance under different types of transmission systems.

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