Audio Watermarking Quality Evaluation: Robustness to DA/AD Processes

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Abstract

Audio watermarking has become an important technology for the recording and advertisement industry. Today's embedding and detection strategies often rely on digital / high quality channels, like CD or mp3. However for numerous applications, watermarks surviving noisy analog environments are better suited or even required. Using such schemes allows to identify audio signals with monitoring devices which are 'listening' to the incoming signals. In the same way, illegal recordings of concerts can be identified.

In this paper we describe a test environment for noisy, acoustic, (analog) channels and present results obtained from a particular watermarking scheme. We identify changes in the affected audio material, like frequency response or the amount of noise added to the signal.

In order to do automatic robustness evaluations of watermarking schemes, the Stirmark Benchmark environment can be used. We analyze if it is possible to simulate an acoustic, noisy DA/AD environment with filters, quantization and noise generators. Based on the presented test results, we identify the parameters relevant for watermarks to successfully survive noisy acoustic channels and thereby provide valuable hints for audio watermark designers. We also describe a design concept for a DA/AD simulation.

1. Motivation

Robustness to DA/AD conversion in conjunction with additive noise is an important feature for audio watermarking schemes and enables new watermarking applications.

Today bootlegging of movies with the help of digital cameras and DIVX compression is a problem the entertainment industry has to deal with. Besides cryptographic methods, watermarking offers a solution to include personalized information into audio-visual material, such as an ID of the cinema a certain copy was sent to. By detecting these watermarks in so-called "screeners", cinemas where movies have been recorded could be identified by the ID carried within the watermark.

While video watermarking is time consuming and many algorithms are still fragile against noise, scaling and rotation, audio watermarking solutions with the required robustness already exist.

On the other hand, use of very robust audio watermarking schemes may cause inherent quality degradations, which still might be acceptable when a mark is hidden e.g. in some of the action scenes of a 90 minute movie.

Other applications for DA/AD robust watermarking schemes include portable audio monitoring devices that could be used to automatically created cue lists from radio stations [1] or music clubs. The controlled toy concept of Digimarc [2] also requires robustness to microphone recordings.

2. Introduction

Digital watermarking is a technology for copyright protection and monitoring unauthorized access and modification of multimedia material. Robust digital watermarking can be used to claim copyright protection by embedding information about authors or producers. Numerous watermarking algorithms have been described. An overview regarding different applications and characteristic parameters is given in [3]. References [4] to [7] provide a selection of audio watermarking algorithms.

With the StirMark Benchmark (SMBM), introduced in [8], we want to provide a well-defined test bench for watermark robustness and security. Researchers and watermark software manufacturers just need to provide a table of results, which gives a good and reliable summary of the performances of the proposed scheme. Thus the end users can check whether their basic requirements are satisfied. Researchers can compare different algorithms and see how a method can be improved or whether a newly added feature actually improves the reliability of the whole method. As far as the industry is concerned, risks can be properly associated with the use of a particular solution by knowing which level of reliability each scheme can achieve. While most research activities

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concentrate on still image watermarking attacks, we identified the need for an audio watermarking evaluation and described first directions and results in [9].
In this paper we concentrate on DA/AD transformations in combination with an acoustic transmission as already mentioned in Section 1. Section 3 describes the test scenario, i.e. evaluating watermarking performance in analog, noisy environments. In Section 4 we provide test results of our experiments. A strategy to include a DA/AD simulation is discussed in Section 5. Influences on the audio material and resulting requirements for audio manipulation attacks are presented there.

3. Test scenario

In this section, we describe our test scenario, i.e. used audio hardware and test environment.
Different commercial evaluation versions of watermarking algorithms were available for the evaluation. However for detailed tests we used our prototypic implementation. The selection of audio files consisted of four different audio signals: classic, pop/rock, spoken text and a kind of noise. The original files were mono and sampled at 44.1 kHz. For audio playback a pair of Yamaha MSP5 monitor speakers were used. Recording was done via four different microphones:

- Kotec KM 150 D: vocal microphone
- Creative Labs: cheap soundblaster microphone
- Shure SM 58: professional microphone.
- Vivanco EM 116: inexpensive microphone for amateur recordings.

Test procedure

1. Embed watermark into audio file
2. Play back audio signals via the speakers
3. Record audio signals with each microphone
4. Detect watermark from the recorded audio signals

We used different distances between speakers and microphones in the range of 5cm to 400 cm (see Figure 1).

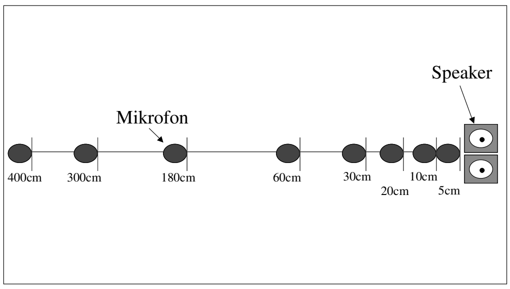

Figure 1: Test environment

Our goal was to evaluate the robustness of the watermark against the described DA/AD conversion. Using the results of our tests we wanted to set up a simulation model which can be added into SMBM. Obviously the characteristics of our test scenario depend on the microphones, speakers and the environment. We used Cool Edit 2000 by Syntrillium for frequency analysis.

4. Test results

In this section, results of our tests will be presented. We discuss the influence of DA/AD conversion and acoustic transmission on the signal characteristics as well as the influence on the embedded watermarks.
Due to limited space we cannot provide all test results in this paper. Please find more results including audio examples at http://www.ipsi.fhg.de/mobile/itcc2002.
Figure 2 shows the power density spectrum of a selected original signal. Figure 3 shows the spectrum of the corresponding recorded signal. We played the audio file with the speakers and recorded it with the microphone KM 150 D.

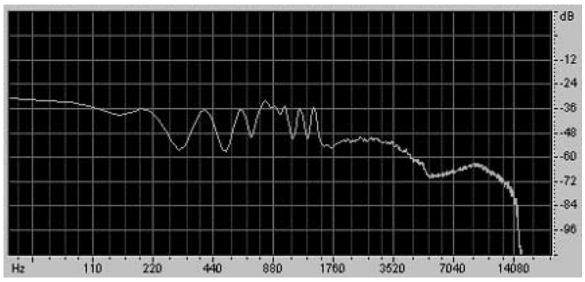

Figure 2: Power density spectrum of original

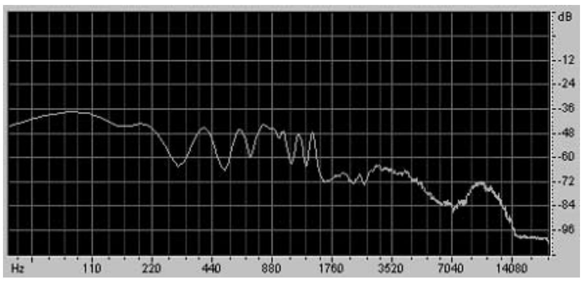

Figure 3: Power density spectrum of recording

In the high frequencies (> 15kHz) the DA/AD conversion added noise to the signal. At low frequencies (< 100 Hz) the DA/AD conversion and the microphone frequency response reduced the signal energy. Figure 4 shows both power spectra in comparison.

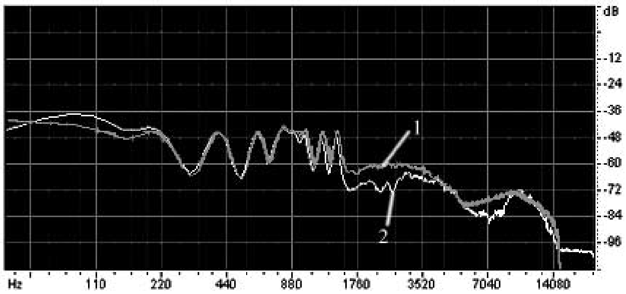

Figure 4: Comparison of original and recorded signal

Curves 1 and 2 represent the original signal and the DA/AD processed and recorded signal, respectively.
The watermarking algorithm under test was a PCM watermarking system developed at the Fraunhofer IPSI, which turned out to be very robust against DA/AD conversion. In some cases we were able to decode the watermark over all tested distances. Note that a comparison to other commercial watermarking systems is difficult because watermarking parameters; such as data rate and perceptual transparency need to be taken into account. It was, however, not the intention of this paper to evaluate different watermarking systems, but to identify parameters of DA/AD conversion in order to set up an automated test with Stirmark.
Table 2 shows the test results for one audio signal and different microphones.

Table 1: Effect of different microphones

Distance [cm]	SB	KM150D	SM58	EM116
5	OK	OK	OK	OK
10	OK	OK	OK	NOT
20	OK	OK	OK	NOT
30	OK	OK	OK	OK
60	OK	OK	OK	OK
180	OK	OK	OK	NOT
300	OK	OK	OK	NOT
>400	OK	OK	OK	NOT

Obviously, the microphone type influences the detection rate. Each microphone has its own characteristic of changing the audio signal. It is interesting to see that the cheap SoundBlaster microphone provides very good results. The next table shows test results recorded with the SM58 microphone and different sound signals.

Table 2: Different audio types with A

Distance [cm]	classic	male	sound	Rock	Female
5	OK	NOT	OK	OK	NOT
10	OK	OK	OK	OK	OK
20	OK	OK	OK	OK	OK
30	OK	OK	OK	OK	OK
60	OK	OK	OK	OK	NOT
180	OK	OK	OK	OK	NOT
300	OK	NOT	OK	NOT	NOT
>400	OK	NOT	OK	OK	NOT

As one can see, the content of the audio signal is also relevant for the robustness of the watermarking algorithm versus DA/AD conversion. Figure 5 shows that only for the signals "classic" and "sound" the watermark is detected at all distances while "female" is only detected three times. Spoken text, which includes gaps between the sound, seems to reduce watermarking robustness in this environment.

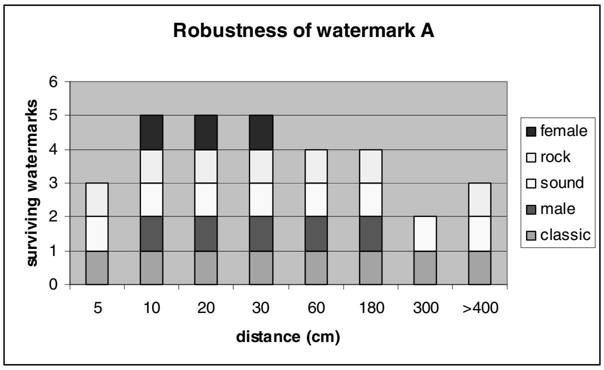

Figure 5: Test results

5. DA/AD SMBM IMPLEMENTATION

It is important to know the effects of DA/AD conversion on audio signals to implement a DA/AD model for the Stirmark benchmark. We now create a model of a DA/AD conversion and use it to simulate the changes to an audio file in this environment.
A complete simulation model should consider the following effects:

1. **Soundcard DA**: Soundcards produce noise and quantization distortion.
2. **Amplification**: The amplification modifies the energy of the signal and adds noise due to internal amplifiers.
3. **Speakers**: All speakers have a specific frequency response, which is applied to the signal.
4. **Environment**: This includes room reverberation and environmental noise like talking in the background. The distance between speakers and microphone has to be taken into account as the loss of quality will increase with it.
5. **Microphone**: The effects of the microphone are similar to the effects of speakers. They impose their frequency response.
6. **Microphone amplification**: Similar to step 2
7. **Soundcard AD**: Similar to step 1

For all components mentioned above we need a simulation. The most important effects which influence the signals are:

- Noise, additive distortions
- Amplitude and phase shift
- Quantization
- Modification of the signal energy
- Filtering effects due frequency responses of applied hardware

Based on our observations this model should by suitable to simulate DA/AD conversion, acoustic transmission and noise addition in SMBM. This attack will be a major challenge to the robustness of digital audio watermarks.

6. Conclusion

In this paper the robustness of audio watermarking algorithms against DA/AD conversions and acoustic transmission in noisy environments was investigated. Based on practical experiments the parameters of acoustic transmission attacks were identified in order to set up a model for automated testing of watermark algorithms with the Stirmark Benchmark (SMBM).
Our test results showed that algorithms can be designed for the high robustness needed to survive this attack. Robustness against this attack enables applications like the cinema movie protection mentioned in Section 1. Testing watermarking robustness against a rather complex attack like the one discussed within a tool like SMBM requires knowledge about simulation parameters. In Section 5 we identified the most important parameters of the attack scenario. They can be used to create a test simulation ranging from simple DA/AD transmissions with a soundcard to microphone recordings in noisy environments.
In the near future we will implement the components currently not provided in the SMBM audio watermarking test suite and will include different DA/AD environments in our list of SMBM attacks.

7. References

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