RESTORATION OF NONLINEARLY DISTORTED OPTICAL SOUNDTRACKS USING REGULARIZED INVERSE CHARACTERISTICS

PhD thesis

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Alulírott, Bakó Tamás Béla kijelentem, hogy ezt a doktori értekezést magam készítettem és abban csak a megadott forrásokat használtam fel. Minden olyan részt, amelyet szó szerint, vagy azonos tartalomban, de átfogalmazva más forrásból átvettem, egyértelműen, a forrás megadásával megjelöltem.

A dolgozat bírálatai és a védésről készült jegyzőkönyv a későbbiekben, a Budapesti Műszaki és Gazdaságtudományi Egyetem dékáni hivatalában lesz elérhető.

Budapest, 2004. június 3.

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Magyar nyelvű összefoglaló

A régi filmfelvételek hangja gyakran nem túl jó minőségű: a lejátszott hang rendkívül zajos és torz. A torzult hang fárasztja a közönséget, akik kevésbé tudnak koncentrálni magára a filmre, ezáltal a film élvezhetősége csökken. Ez az oka annak, hogy számos régi filmet nem érdemes lejátszani a közönségnek a televízióban vagy a filmszínházakban. A torz hangot azonban digitális jelfeldolgozási módszerekkel jobbá lehet tenni.

Mivel a hangrestaurálás számára semmi más nem áll rendelkezésre, csak a torz és zajos filmfelvétel, és nincs hozzáférésünk sem az eredeti jelhez, sem pedig a készülékekhez, amivel a felvételt készítették, ezért az egyetlen lehetőségünk a hangminőség feljavítására a hang utólagos kompenzálása. Ez a disszertáció új módszereket javasol az optikai úton rögzített régi filmek nemlineárisan torzult hangjának hatékony és gyors utólagos kompenzálására.

A disszertáció első részében a nemlineáris modellekről és a nemlineáris kompenzáló technikákról esik szó, majd az utólagos nemlineáris kompenzálás lesz részletesen elmagyarázva és az, hogy ez a probléma miért ún. rosszul kondícionált probléma. A disszertáció második részében olyan módszerek lesznek bemutatva, melyek képesek kezelni a probléma rosszul kondícionáltságát (a hang helyreállítás érzékenységét a torz jelhez hozzáadódott zajokra). A módszer hatékonyságát szimulációk és filmrészletek hangjának helyreállítása támasztják alá.

To the muse

Dóra Szász

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Keywords

The following keywords may be useful for indexing purposes:

Audio restoration, nonlinear compensation, regularization methods, Tikhonov regularization, optical soundtrack, density characteristic.

Summary

This dissertation is concerned with the possibilities of restoration of degraded film-sound. The sound-quality of old films are often not acceptable, which means that the sound is so noisy and distorted that the listener have to take strong efforts to understand the conversations in the film. In this case the film cannot give artistic enjoyment to the listener. This is the reason that several old films cannot be presented in movies or television.

The quality of these films can be improved by digital restoration techniques. Since we do not have access to the original signal, only the distorted one, therefore we cannot adjust recording parameters or recording techniques. The only possibility is to post-compensate the signal to produce a better estimate about the undistorted, noiseless signal. In this dissertation new methods are proposed for fast and efficient restoration of nonlinear distortions in the optically recorded film soundtracks.

First the nonlinear models and nonlinear restoration techniques are surveyed and the ill-posedness of nonlinear post-compensation (the extreme sensitivity to noise) is explained. The effects and sources of linear and nonlinear distortions at optical soundtracks are also described. A new method is proposed to overcome the ill-posedness of the restoration problem and to get an optimal result. The effectiveness of the algorithm is proven by simulations and restoration of real film-sound signals.

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Chapter 1

Introduction

1.1 Overview

The optical filmsound-recordig technology is more than 100 years old. Since then millions of sound-films were made and then stored in the national film archives, which have inestimable artistical value. The task of the archives is not just to preserve these films but also to prepare them for broadcasting and show them to the wide audience. However, most of these films cannot be broadcasted because they suffer from several degradations.

There are several distinct types of film degradations. These can be broadly classified into two groups: localised degradations and global degradations. Localised degradations are discontinuities in the waveform which affect only certain samples. Global degradations affect all samples from the waveform. We can distinguish the following sub-classes of degradations [1]:

– clicks and cracklings,

– low-frequency noise transients,

– broad band noise,

– wow and flutter,

– non-linear defects.

Clicks and cracklings are short bursts of interference random in time and amplitude. The cause of these impulsive disturbances are mutations on the sound-carrier material (e.g. scratches or dirt spots on the surface).

Low-frequency noise transients are mainly larger scale defects than clicks. The reasons are large discontinuities due to glued parts of film-rolls or other strong damages at optical sound-recording. These changes in the film material cause special excitations in the light intensity during sound reproduction and hence cause strong transients in the reproduced sound. These large discontinuities can be heard as low-frequency pulses.

Broad band noise is common to all analogue measurement, storage and recording systems and in the case of audio signals it is generally perceived as "hiss" by the listener. It can be composed of electrical circuit noise, irregularities in the storage medium and ambient noise from the recording environment.

Wow and flutter are pitch variation defects which may be caused by eccentricities in the playback system, motor speed fluctuations or by special distortions of the sound carrier (e.g. shrinkage of film).

Non-linear defect is a very general class that covers a wide range of distortions. In the audio field, the principal causes are [2]:

– saturation in magnetic recording,

– tracing distortion (before compensation was introduced) and groove deformation in records,

– the inherent nonlinearity of optical soundtracks.

There are already many solutions and applications in the scientific literature and on the market that deals with restoration of local degradations and wide band noise. There are already several results published in the literature to eliminate pitch defects. However, there was a relatively small emphasize on the elimination of non-linear defects. It is the topic of current research interests in DSP for audio [1].

In the last decade, methods restoring damaged audio recordings have progressed from ad hoc methods, motivated primarily by ease of implementation, towards more sophisticated approaches based on mathematical modeling of the signal and degradation processes.

This thesis addresses the elimination of distortion of optical soundtracks, a previously not too extensively investigated problem. Restoration of nonlinear distortions is a special kind of inverse filtering problem. This problem could be ill-posed, which means that during reconstruction of the nonlinearly distorted signal, small uncertainties in this signal can cause strong deviations in the restored one. In this case, our aim is to find a restoration method, where both the signal distortion and the level of deviation (more simply the level of the amplified noise) can be kept low. The aim of this dissertation is to clarify the reasons of nonlinear distortions in the case of optical soundtracks and propose methods based on digital signal processing to reduce the distortion and avoid the appearance of artefacts in the restored sound.

1.2 Structure of thesis

Chapter 2 introduces the description and representation forms of memoryless nonlinearities and nonlinearities with memory. Chapter 3 examines the possible methods for eliminating effects of nonlinear distortions and explains in details the problems and possible solutions of nonlinear post-compensation techniques. The main problem during post-compensation is the amplification of the noise that is present in the original material. Without proper compensation, the noise amplification could be so strong that the resulted sound could be worse than the distorted one. In this chapter the origin of the noise amplification is discussed and the possible methods are summarized, which could be applicable to overcome this problem.

Chapter 4 reviews the nonlinear characteristic of photosensitive materials and shows the analytical equations, which describe the nonlinear behaviour. Chapter 5 discusses the film-sound recording techniques and the appearance of nonlinear distortions of the photosensitive materials in the sound.

Chapter 6 shows two novel methods for composing compensation characteristics for post-compensation of distorted signals. One of them is based on Tikhonov regularization operators. The aim of this compensation technique is to minimize the estimated value of the energy of noise and distortion terms together. The method is fast compared to other compensation methods, because this method does not have iterative steps during the compensation process. Simulations also show in this chapter that the accuracy of the method is as high as other compensation methods.

A common problem at regularization of an ill-posed problem is that we have a very little knowledge about the original signal, hence we don't know, how much regularization is needed to achieve the optimal result. In this chapter a new method is shown that can automatically find a good estimate about the amount of regularization without the interaction of a user. It is quite important at the film industry and at the film archives, where huge amount of degraded films are waiting for restoration and there is no time to make several experiments on each film.

The aim of the second compensation method is to produce an unbiased estimate from the noisy, distorted signal about the original, undistorted one.

We also have little knowledge about the nonlinear distortion function, which is another problem in signal compensation. In chapter 6 a possible method is shown for the identification of the nonlinear function in the knowledge of an analytical, parametrizable formula about the distortion.

Finally, Chapter 7 presents conclusions and suggests possible directions for future research.

Chapter 2

Just for fun

A system, at which the relation between the input and the output of the system is described by the function $H()$, is a linear system if, for any inputs $x_1(t)$ and $x_2(t)$, and for any constant, c, the additive property (eq. (2.1)) and the homogeneity property (eq. (2.2)) are satisfied:

$$H(x_1(t) + x_2(t)) = H(x_1(t)) + H(x_2(t)), \tag{2.1}$$

$$H(c \cdot x(t)) = c \cdot H(x(t)). \tag{2.2}$$

In the case of a nonlinear system the additive and/or homogeneity properties are not satisfied.

At variable density recording a thin light ray is projected to the constantly moving film-band and the intensity of the light ray is controlled by the sound signal (Fig. 2.2). Since creation of movie pictures require not constant movement, therefore creation of sound stripe and creation of picture are made in two different modules of the movie camera (sometimes they are made on even two different film rolls). The sound record on the sound-film will be displaced from the center of the corresponding picture by a distance of 21 frames [3, 4]. However, this effect will not cause any additional problem in copying of the film or cause any additional distortions and we don't have to deal with the picture module of the camera in the followings. Therefore Fig. 2.2 shows already only the sound projection part.

During sound-recording, the controlled light shined through a narrow slit onto the moving film, which was kept running at a constant speed (Fig. 2.2). The film speed was different at

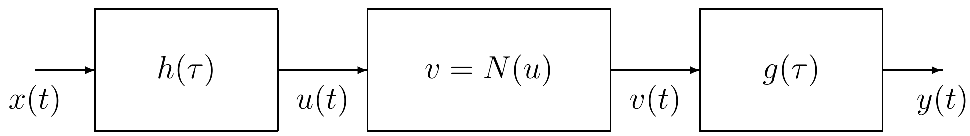

Figure 2.1: Block diagram of an LNL system.

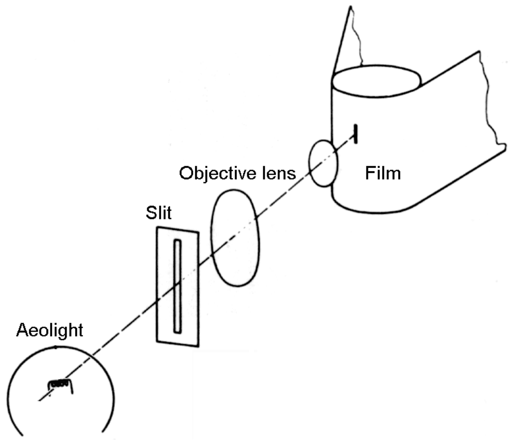

Figure 2.2: Schematic diagram of variable density method.

Table 2.1: Velocity of different film formats.

Format	Velocity [mm] at different image number per second			
	25	24	18	16
70	–	570	–	–
35 (standard)	475	456	–	304*
16 (sub-standard)	190.5	182.8	137	122
8S	105.7	101.5	76.1	67.7

* Only for silent films.

different film formats. Speeds for the standard film formats can be seen in Table 2.1 (data is taken from [5]).

The gap width of the slit in the case of 35 mm film is about 20 μm. The image of the slit is reduced and projected to the film by a lens. The gap width on the image is about 10 μm, the width of the soundtrack itself in the case of variable area method is 2.94 mm, the scanned area at sound reproduction is only 2.13 mm [4, 6].

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