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Development of an Error Correction Technique for Audio Signals Recorded on Optical Compact Disk

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AOA and SAA designed the study and wrote the first draft of the manuscript. Authors SAA and RAB managed literature searches. Authors AOA, SAA and RAB carried out the simulation and interpreted the results. All authors read and approved the final manuscript.

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ABSTRACT

The occurrence of high random bit error rates alongside long burst errors in playback audio signal recorded on compact disk (CD) poses a problem beyond what the usual Cross Interleaved Reed-Solomon Code (CIRC) may handle. In this paper we propose a technique that makes use of the orthogonality properties of Walsh code to handle these types of errors. Results obtained show that the technique can correct for burst errors exceeding 7000 bits and random errors at Signal to Noise Ratio of -5dB at the recording channel. This performance exceeds that of CIRC in terms of maximum correctible burst error length and random error correction rate. The proposed technique will effectively correct long burst and high random bit errors in playback audio signals recorded on optical CD.

Keywords: Walsh code; random error; burst error; CIRC; audio signal.

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1. INTRODUCTION

Over the past three decades, digital audio has evolved as a primary driving force in audio production, entertainment, and communication [1]. The introduction of optical storage disk has made Audio CD's one of the de facto standards for the storage of digital audio signals [2]. Pulse Code Modulation (PCM) has been the dominant technique for digital audio coding on optical disk [3], but the extremely high density of stored information within a PCM recording and playback system makes it highly susceptible to the occurrence of random and burst errors [1]. Such occurrence is common in many digital audio recordings including the magnetic and optical audio recording media [4].

It has been shown that existing techniques will correct burst errors but would not correct high random error rates alongside burst errors [5-7]. CIRC is actually incapable of correcting such errors as its maximum correctible burst error length is 4000 bits [8] and this value assumes that there are no random errors near (i.e. within 28 frames). Even then similar techniques used in correcting random errors are inefficient when applied to correct burst errors [9]. Concatenated techniques like [10] are inefficient when applied to correct long burst errors and high random bit error rates when they occur together. Unfortunately both errors occur together in most practical system [11]. This work aims at filling this gap.

In the ensuing technique, we employ the orthogonality of Walsh code to correct for any error anomaly from the playback process. Walsh codes are a class of perfectly orthogonal codes with economical computational cost [12], other properties of Walsh codes can be found in [13]. Some areas of applications of Walsh code include watermarking, DS-CDMA, cryptography and electrical impedance tomography [14-17].

2. PROPOSED TECHNIQUE

Figs. 1 and 2 show the block diagram for the implementation of both audio recording and playback processes respectively. The pilot signal $p(t)$and the audio signal $s(t)$are recorded in an orthogonal manner by multiplying each signal with Walsh code W_j of different indices m and n to guarantee orthogonality. This facilitates easy recovery of the pilot signal from the composite signal $x(t)$ at the playback end. The recovered playback pilot signal$p^{'}(t)$ is compared with a referenced pilot signal $p(t)$and the difference $e(t)$ is used to correct any error in the playback signal$s^{'}(t)$ after correcting for timing errors.

2.1 Recording and Separation of the Composite Signal at the Playback End

Consider the digital audio recording system shown in Fig.1.The pilot signal $p(t)$ and the audio signal $s(t)$ are multiplied with Walsh code $W_j$of different indices m and $n$to guarantee orthogonality. The composite signal is the recorded signal.

$$x(t) = s(t)W_j^n + p(t)W_j^m \tag{1}$$

At the playback end, the recovered signal is

$$r(t) = x(t) + n(t) \tag{2}$$

$$= s(t)W_j^n + p(t)W_j^m + n(t) \tag{3}$$

where $n(t)$ is the distortion effect that occurred over the recorded channel. At the playback side the playback audio signal is separated from the composite signal by correlating with the Walsh code as shown in Fig. 2. The output of the playback pilot signal path after correlation is

$$p^{'}(t) = \sum_{k=1}^{j} r(t)W_j^m(k)$$

$$= \frac{1}{j}\sum_{k=1}^{j}\Big(s(t)W_j^n + p(t)W_j^m + n(t)\Big)W_j^m(k) \tag{4}$$

$$= s(t)\frac{1}{j}\sum_{k=1}^{j} W_j^n W_j^m(k) + p(t)\frac{1}{j}\sum_{k=1}^{j} W_j^m W_j^m(k) + n(t)\frac{1}{j}\sum_{k=1}^{j} W_j^m(k)) \tag{5}$$

$$p^{'}(t) = p(t) + n(t)W_j^m \tag{6}$$

(Since $\sum_{k=1}^{j} W_j^n W_j^m(k) = 0 \text{ for } m \neq n$, the first term in equation 5 becomes zero).

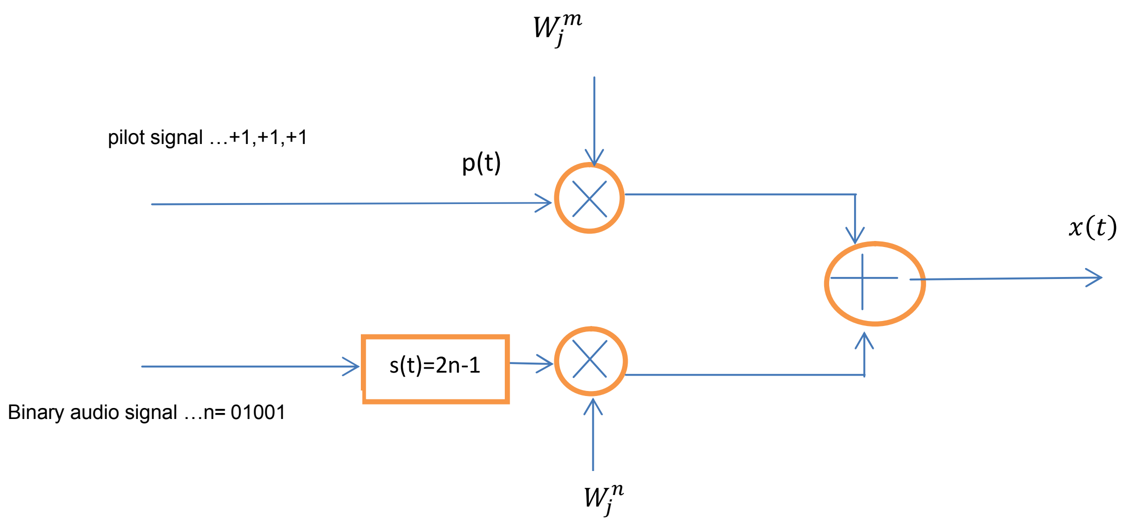

Fig. 1. Proposed recording technique

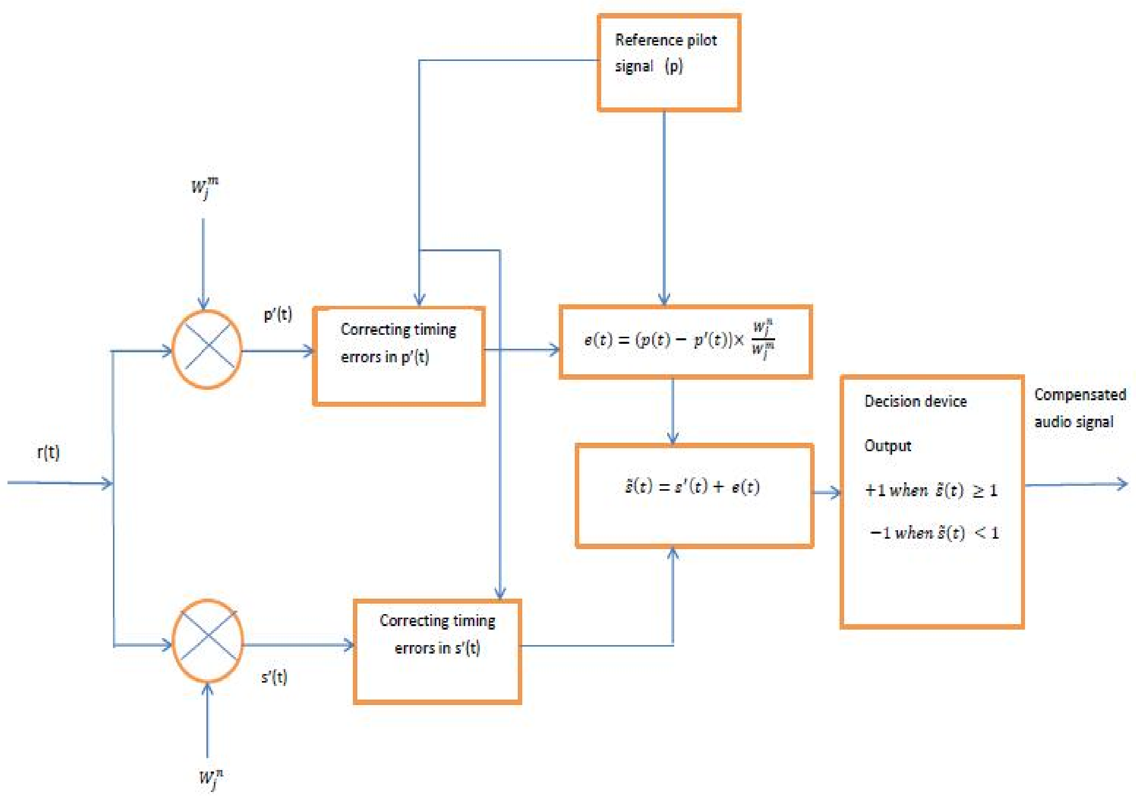

Fig. 2. Proposed playback technique

The output of the playback audio signal path after correlation can be written as

$$s^{'}(t) = \frac{1}{j}\sum_{k=1}^{j} r(t)W_j^n(k) \quad (7)$$

$$= \frac{1}{j}\sum_{k=1}^{j}\left(s(t)W_j^n + p(t)W_j^m + n(t)\right)W_j^n(k) \quad (8)$$

$$= s(t)\frac{1}{j}\sum_{k=1}^{j} W_j^n W_j^n(k)$$

$$+ p(t)\frac{1}{j}\sum_{k=1}^{j} W_j^m W_j^n(k)$$

$$+ \quad n(t)\frac{1}{j}\sum_{k=1}^{j} W_j^n(k)) \quad (9)$$

$$s^{'}(t) = s(t) + n(t)W_j^n \quad (10)$$

2.2 Correction for Timing Errors

Correction for timing error is important to ensure that the playback pilot signal and the playback audio signal are synchronized in time with the reference pilot signal at the playback end.

The cross-correlation function between the referenced pilot signal $p(t)$ and the playback pilot signal $p^{'}(t - \tau_p)$ is

$$R_{pp^{'}}(\tau) = E\left[\, p(t)p^{'}(t - \tau_p)\right] \quad (11)$$

where E is the expectation operator and τ_p is the time lag between $p(t)$ and $p^{'}(t)$.The maximum of $R_{pp^{'}}(\tau)$ represents the estimated time delay D_P

$$D_P = \arg max\left[R_{pp^{'}}(\tau)\right]. \quad (12)$$

This is used to correct for the timing errors in the playback pilot signal. Similarly for timing error correction in the playback audio signal, the cross correlation function between the referenced pilot signal $p(t)$and the playback audio signal $s^{'}(t - \tau_a)$ is

$$R_{ps^{'}}(\tau) = E\left[\, p(t)s^{'}(t - \tau_a)\right] \quad (13)$$

where $\tau_a$is the time lag.

$$D_s = \arg max\left[R_{ps^{'}}(\tau)\right]. \quad (14)$$

This is used for correcting timing errors in the playback audio signal.

2.3 Error Compensation

The error signal is computed from the reference and playback pilot signal as

$$e(t) = p(t) - p^{'}(t)$$
$$= p(t) - \left(p(t) + n(t)W_j^m\right)$$

$$= -n(t)W_j^m \quad (15)$$

$$e(t) = \ -n(t)W_j^m \times \frac{1}{W_j^m} = -n(t) \quad (16)$$

multiplying equation 16 with W_j^n

$$e(t) = \ -n(t) \times W_j^n \ = -n(t)W_j^n. \quad (17)$$

The compensated playback audio signal $\tilde{s}(t)$is

$$\tilde{s}(t) = s^{'}(t) + \left(e(t)\right) = s(t) + n(t)W_j^n - n(t)W_j^n. \quad (18)$$

$\tilde{s}(t)$is fed into the decision device which outputs;

$$+1\ when\tilde{s}(t)\ \geq 0$$
$$-1\ when\tilde{s}(t)\ < 0$$

The compensated playback audio signal is converted back to binary by the mapping:

$$1 \rightarrow 0, -1 \rightarrow 1.$$

3. RECORDING CHANNEL

For the evaluation of random error correction, the recording channel was modeled as an AWGN channel. For the evaluation of burst error correction, a modified Gilbert model that allows for soft decision decoding as employed in [18], was used to model burst error in the recording channel. The model has two states of good (*G*) and bad (*B*) and uses two distinct SNRs (one for the good and the other for the bad).

In the good state, data transmission was modeled as almost error free and in the bad state it was modeled as having a low SNR (which implies many bit errors and almost no information was transmitted). One-dimensional (1-D) burst error was used and the experiments were carried out via computer simulations.

4. RESULTS AND DISCUSSION

Evaluation of the developed recording and playback technique was carried out using a digital playback audio signal with a sampling frequency of 44,100 Hz and PCM encoded using

16 bits per sample. The playback signal was distorted with random errors, burst errors and a combination of burst and random errors. Results were obtained using the parameters shown in Table 1. Results obtained when there is high random error rate, long burst error and a combination of high random error rate and long burst errors in the recording channel are as indicated in Figs 3, 4 and 5 respectively. Computed bit error rate for the recovered audio signal in figures 3 to 5 was 0.0. This shows that the developed technique was able to correct for burst errors, random errors and a combination of burst and random errors in the distorted playback audio signal.

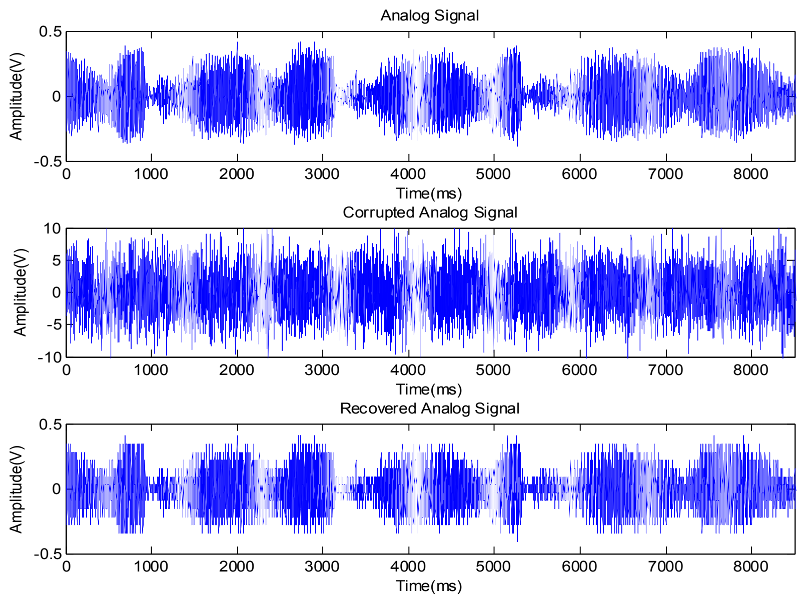

Fig. 3. Analog representation of the recorded audio signal (a), the distorted playback audio signal (b) and the recovered audio signal (random error) (c)

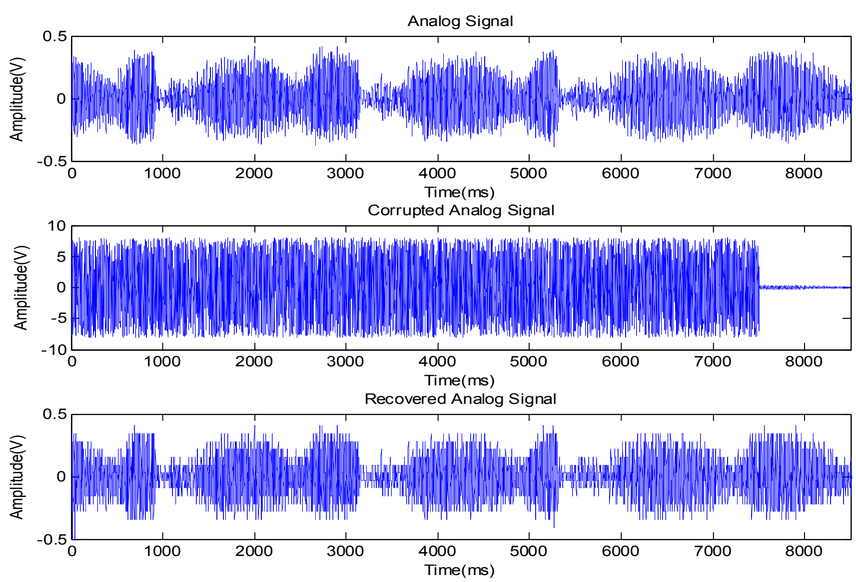

Fig. 4. Analog representation of the recorded audio signal (a), the distorted playback audio signal (b) and the recovered audio signal (burst error) (c)

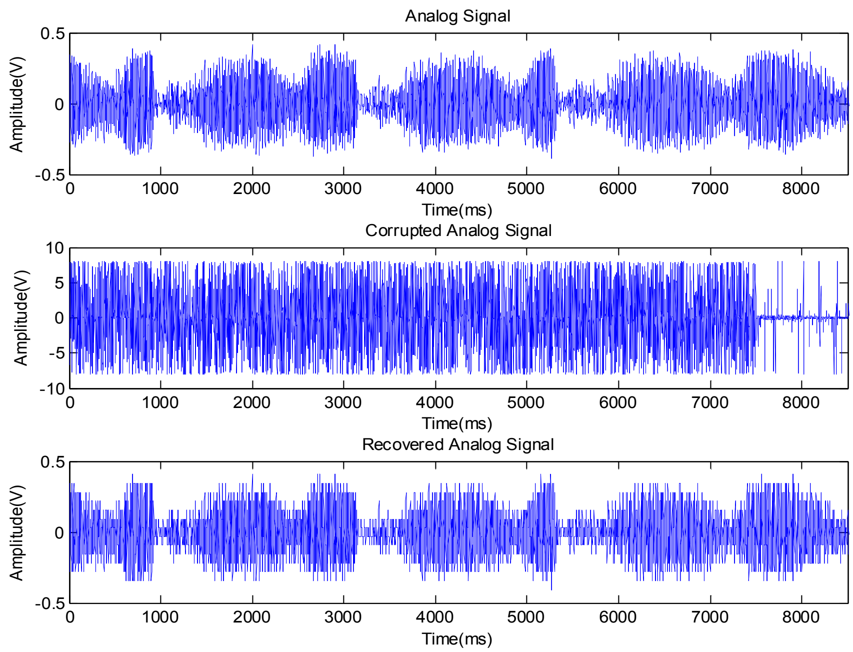

Fig. 5. Analog representation of the recorded audio signal (a), the distorted playback audio signal (b) and the recovered audio signal (burst and random error) (c)

Table 1. Simulation parameters

Type of error	Noof samples	Burst error length	Error free length	SNR_{good}	SNR_{bad}	AWGN
Burst only	8500 bits	7500 bits	1000 bits	30dB	-10dB	
Random only	8500 bits					-5dB
Burst and Random	8500 bits	7500 bits	1000 bits	30dB	-10dB	-5dB

The maximum fully correctable burst error length of CIRC and Multilayered Reed Solomon code developed by [5] are 4000 bits and 6872 bits respectively. These values assume that there are no other imperfection or random errors near (i.e. within 28 frames) of the error burst, as such will degrade the above values. The works of [6] and [7] are only effective with short burst error (single burst error with maximum of three symbols) but ineffective with long burst errors and random errors, while [10] is effective with burst and random errors but cannot handle long burst errors and high random bit error rate. Comparison shows that the performance of the developed technique exceeded that of CIRC, and the works of [5-7] and [10] in terms of maximum correctible burst error length and random error correction rate.

5. CONCLUSION

The developed technique effectively corrected for high random bit error rates occurring alongside long burst errors in digital audio signal. Burst error correcting capability exceeded 7000 bits and random errors at SNR of -5dB was corrected by the technique. Comparison with CIRC shows that the performance of the developed technique exceeded that of CIRC in terms of maximum correctible burst error length.

It can be concluded that the application of the orthogonality properties of Walsh code for error correction as shown in this work can effectively correct for high random bit error rates occurring alongside long burst errors in digitally recorded audio signals. This hitherto had been a challenge for digital audio signal recorded on optical CD's. This technique will be valuable in error correction for optical audio CD's and other optical recording platforms such as DVD's and multi-level optical storage systems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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