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Audio watermarking scheme with dynamic adjustment in mute period

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ABSTRACT

Watermark is some imperceptible information embedded into the work for later verification and thus it can be used to prove the originality or to protect the work from being illegally copied or modified. Kaabneh and Youssef (2001) proposed a muteness-based watermarking method for audio file. Their method can successfully embed watermarking information into audio file such that the human ears cannot distinguish the covered work from the original one. To improve the efficiency, we proposed a watermarking method for audio files in this paper. By adjusting the length of mute period dynamically, the proposed method can achieve the goal of watermark embedding with little variation of the original work. Experiment has shown that our method has the advantages of efficiency and fidelity as compared with theirs. Furthermore, it does not require the original audio file to derive the embedded watermark.

1. Introduction

With the continuous improvement of information technology (IT) and the increasing efficiency of computer facilities, more and more IT tools are available for human daily life. Take multimedia applications for examples. To draw a picture or to edit a song, we can use the computer software to assist us in some tedious works or precise tasks. Inevitably, IT also equips the adversary with copy or pirating tools. Furthermore, the popularity of Internet and increasing bandwidth accelerate such violations. As a result, it is very common to hear of the discussion about intellectual property protection against illegally coping.

Digital watermarking (Zeng, 1998), one kind of information hiding, is one of the alternatives used to protect digital rights of most multimedia files, such as image, audio, or video files. With this technique, some delicate information can be embedded into the file and the information can be extracted for certain usages, such as for ownership verification or access authorization. Some applications of digital watermarking are listed below (Zeng, 1998):

1. *Identification of ownership:* The creator or owner could insert certain identification information relevant to himself/herself to media files so that it could be extracted by watermarking detector to demonstrate the ownership when questioned.
2. *Fingerprinting:* The digital watermark is like a fingerprint. The identity of buyer and purchasing information can be packed into the embedding message. In case of a later dispute, this fingerprint can be used to trace back the illegal distributor.
3. *Conveying copyright information:* The digital watermark could be treated as the copyright information that is embedded into the media file. It conveys copyright information linking to some more detailed information about the copyrighted material such as the owner's contact profile, which helps with the determent of copyright infringement.
4. *Copyright monitoring:* With a copyright monitor, owners can search the Internet to look for the watermark of the copyright information and find out unauthorized or inappropriate usages of his/her image without royalty payment.
5. *Copy preventing:* The digital watermark can also be used to prevent unauthorized copy or playback. Installed in the compliant machine, for example, the embedder can embed a watermark into a DVD indicating that the disc is allowed no copy or a single copy. Further, the built-in detector will not allow the machine to play the copy version of a DVD, which reduces the value of the illegal copies.
6. *Embedding relevant information:* The digital watermark can provide some relevant information about the content. For example, it embeds some profile information such as object shape, production date, etc. The information can be used to identify the content or some other usage.
7. *Authentication:* The digital watermark can be used as an authenticator. Once the watermarked file is modified, the extracted watermark would be also damaged. It might further give the

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information of where or to what extent the file is modified. In some applications, we might also require that the watermark survive some specific processing such as compression.

Partly because of the ease of presentation, quite a lot of research literatures focused on research of image watermarking techniques. There are relatively small amount of studies dedicated to the watermarking for audio and video. However, the protecting measures for audio and video media are still in great need. Embedding messages in the least significant bits (LSB) might be one of the simple ways to embed information. Since the LSB only has little effect on the presentation of the media, it is hard for human perception to tell the difference when the LSB is modified. Cvejic and Seppänen (2004) applied the LSB to design an audio steganography scheme for information hiding. Nevertheless, LSB is not so robust against active attacks. Uludag and Arslan (2001) proposed an audio watermarking scheme using DC level shifting to embed one bit information in the DC level of the sound frame. We shift the sound frame toward positive direction to embed 1 and negative direction 0. It only needs to compute the sampling mean of all audio frames of the file when decoding. If the mean is above/under some threshold value, 1/0 is embedded; otherwise, no information is embedded. Megias, Herrera-Joancomarti, and Minguillon (2003) utilized the difference between the compression and decompression of MP3 to embed information (Megias et al., 2003). The watermark is inserted into some pre-selected positions in the processed file. If 0 is embedded, the signal is reduced by n dB; if 1 is embedded, the signal is increased by n dB. By means of the mute period of the audio file, Kaabneh and Youssef (2001) proposed an audio watermarking scheme. The mute period is one characteristic of the sound, for example, it might be the interval between sentences or break between syllables. They embedded the watermarking information in the file by modulating the length of mute period. The information can be extracted by subtracting the mute period of the watermarked file from that of the original one.

To enhance the security, in this paper, we proposed an audio watermarking scheme based on the mute period which may contain some noises that are unperceivable by the human auditory system (HAS). Using mute periods as the positions for embedding the watermarking information can prevent an attacker from easily detecting where the watermark is. We slightly modify the manipulation process which results in a great improvement of performance as compared with the Kaabneh–Youssef scheme. For a better understanding of audio file's watermarking technology, we first give some requirements (Kaabneh & Youssef, 2001):

(i) The embedded watermarking information shall be unperceivable. It is usually a tradeoff between the fidelity and the robustness. That is, more embedded watermarking information could result in more distortion and more robustness, and vice versa.
(ii) The watermarking system should be robust enough against general digital processing, such as loss compression, filtering, re-sampling, digital/analog conversion, and noise inserting.
(iii) The system can meet the requirement of multiple watermarks. In other words, the original file can be embedded several different watermarking information such that each of the watermarks can be separately detected.
(iv) The attacker cannot derive the embedded watermarking information by means of analyzing many watermarked files in which the same information is embedded.
(v) It is infeasible for the attacker to remove the embedded watermarking information.

The human auditory system (HAS) has an audio perception frequency range from 20 Hz to 20 kHz (Kaabneh & Youssef, 2001; Xu, Zhu, & Feng, 2001). The watermarking information cannot be embedded outside this range, or it can be easily removed or filtered out through the processing of audio signal. Therefore, it is a challenging task to hide watermarking information in audio file; however, it should be an important segment in future applications.

The rest of the paper is organized as follows. Section 2 is the description of some literature reviews. Section 3 will introduce the proposed audio watermarking scheme. Some experiments and analyses according to the proposed method are given in Section 4. Finally, we make a conclusion in Section 5.

2. Literature review

In the section, we introduce the manipulation of digital watermarking and review the muteness-based method proposed by Kaabneh and Youssef (2001). The digital watermarking is seen as a possible solution to the problem of copyright protection. In general, watermarking techniques can be classified into two broad categories: spatial-domain-based and frequency-domain-based ones. The former watermarking techniques embed the watermark into the host image by directly modifying the pixel value of the host image without causing obvious change in appearance. By modulating the least-significant bit (LSB), the human visual organ is not sensitive to the difference because the change in intensity of certain pixels is small. Several schemes were proposed by using statistic method, LSB (Chan & Cheng, 2004), and adjusting the value of blue color tone. The latter watermarking techniques embed the watermark by modulating the magnitude of coefficients in a transform domain, such as discrete cosine transform (DCT) (Barni, Bartolini, Cappellini, & Piva, 1998), discrete Fourier transform (DFT), discrete wavelet transform (DWT) (Suhail, Obaidat, Ipson, & Sadoun, 2003; Tsai, Hu, & Chang, 2004; Víctor, Mariko, & Héctor, 2004), etc. Then, the transformed frequency coefficients are modified to embed the desired watermark. Finally, the inverse transform function is performed.

Kaabneh and Youssef (2001) proposed a watermarking scheme for embedding watermarks in audio file. They utilized the mute periods of audio files as the positions for information hiding. The characteristics of the mute period are (i) it is an inevitable segment of any audio file and cannot be omitted; (ii) it occurs randomly in an audio file; (iii) it represents a time span that will not be decreased by compression. Usually, there must be some mute periods in audio files such as the break of sentences or phases in speech clips and the rest in music files. All these mute periods are considered as the necessary parts of any song or speech and cannot be negligent or omitted. Note that, the mute period still may contain noises. However, such noises are imperceptible by the human auditory system (HAS). We briefly describe the Kaabneh–Youssef scheme as follows.

At the beginning, we first search all mute periods in an audio file and record the length of the ith mute period as $M(i)$. Then determine the variation amount $\delta(i)$ of each $M(i)$ according to the information of embedded watermark. Finally, compute the new mute period $M_w(i)$ with the embedded watermark as Eq. (1)

$$M_w(i) = M(i) + \delta(i). \tag{1}$$

Without using the original audio file, their scheme only requires the length of each mute period of the original file to detect the embedded watermark. From the distribution copy of the audio file, we can extract all the lengths of all mute periods $M_w(i)$'s and calculate each variation amount $\delta(i)$ as Eq. (2).

$$\delta(i) = M_w(i) - M(i). \tag{2}$$

It can be seen that, in the Kaabneh–Youssef scheme, the length of mute periods is increased with the amount of variation, which results in a size expending of the file. In addition, their scheme has to record all the lengths of mute periods of the original file for extracting the watermark. In the next section, we will propose an efficient audio watermarking scheme to eliminate these drawbacks.

3. Our proposed method

We use the dynamic adjustment in mute period (DAMP) to embed watermarking information into audio files. Since we modify the length of mute periods to encode messages and dynamically modulate each mute period, the length expansion of the audio file can be reduced to the minimum. Our approach needs three predefined parameters including the threshold amplitude of mute periods (db_T), the threshold lasting time of the mute periods (L_T) with respect to the corresponding db_T, and the slice unit (S_u) for mute periods derived from the shortest mute period. With these three values, we can extract the watermark without the original audio file. The proposed scheme can be divided into two procedures: the watermark embedding and the extraction procedures. Details of them are given as follows.

3.1. Watermark embedding procedure

Fig. 1 depicts the diagram of our watermark embedding procedure. First of all, we find out all mute periods of the audio file and record their lengths. Then, by seeking the minimum length of mute period and determining the number of slice n, we can compute the value of S_u. Finally, we embed the message into the audio file to complete the whole procedure. For facilitating the practical implementation, we give the detailed pseudo code, DAMP-E, of the watermark embedding procedure in Appendix.

3.2. Watermark extraction procedure

The extraction procedure of embedded watermark is shown in Fig. 2. With the threshold values of L_T and db_T, we first find all mute periods of the watermarked audio file. Then we utilize the critical value S_u to extract the watermark from each mute period. The detailed pseudo code, DAMP-R, of the watermark extraction procedure is given in Appendix.

4. Experiment designs and analyses

In the section, we will verify the feasibility of our proposed scheme and analyze the significance of the three critical values

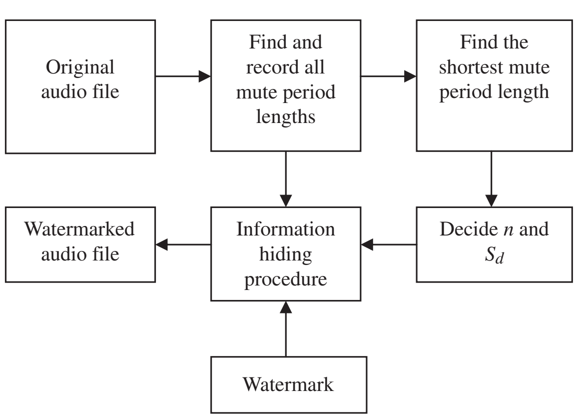

Fig. 1. Watermark embedding diagram.

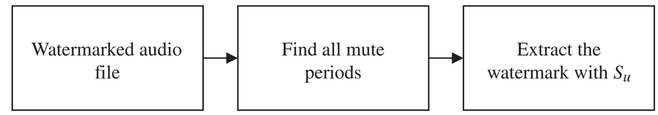

Fig. 2. Watermark extraction diagram.

db_T, L_T and S_u in the watermark extraction procedure. We compare the Kaabneh–Youssef scheme with ours in terms of the capacity of watermarking information, the length expansion and the information capacity required for examination. Based on the same information content and selection standard of mute periods, we design the following experiments and analyze the results.

In the first experiment, we select four different audio files, namely the WAVE files of chant, Erhu Fiddle, Chinese Zither (Guzheng) and Traditional Chinese music for experimenting. All these audio files are stereo with the sampling frequency of 44.1 kHz and the sampling size of 8 bits. Then, we use one paragraph of words as the watermarking information to embed it into the above audio files with the Kaabneh–Youssef scheme and ours, respectively.

In the second experiment, we choose two audio files: one is the SONGBIRD played by Kenny G. in his saxophone album "Greatest Hits" published in 1997, which is a stereo WAVE file with the sampling frequency of 44.1 kHz and the sampling size of 16 bits; the other is the Declaration of Independence read by the President Kennedy, which is downloaded from the website of JFK Library and Museum (http://www.jfklibrary.org/audio/-jfk_declaration_independence.rm). We then further convert this file into stereo WAVE format with the same sampling frequency and size. In this experiment, a picture is picked as the watermark. We illustrate the experiments in details as follows.

4.1. Analyses of the first experiment

In the experiment, the text of "Fo Guang University" is used as the watermarking information. We first transform the text into bit streams and then repeatedly insert them into all mute periods. The experiment results are demonstrated as Tables 1–4. Some analyses are given below.

4.1.1. The capacity of watermarking information

As shown from Tables 1–4, it can be seen that under the same L_T value, the higher the value db_T, the more capacity of the watermarking information it can embed. This is because increasing db_T results more mute periods, so as to increase the capacity. Yet, if it db_T is too large, the quality of audio might be decreased. By setting equivalent L_T and db_T values, in this experiment, both the Kaabneh–Youssef scheme and ours can obtain the same number of mute periods. Besides, we use the identical information content for embedding. Consequently, it comes out the equal capacity of watermarking information with two schemes.

4.1.2. The expansion of audio file

According to Tables 1–4, one can see the difference of length expansion between the two schemes. With the proposed scheme, it is 0 ms for all audio files. With the Kaabneh–Youssef scheme, however, it is increased by 102 ms at most and 2 ms at least for different audio files. Obviously, the proposed scheme can effectively reduce the length expansion compared with theirs. Further, consider the factor of the capacity of watermarking information. Since the proposed scheme dynamically modulate the mute period, the length expansion is slight or even none when the watermarking

Table 1
The 1st test of Experiment 1.

	Medium length (ms)	Capacity (bit)	Length expansion (ms)		Overhead information (byte)		SNR (dB)		ASNR (dB)	
			DAMP	KY	DAMP	KY	DAMP	KY	DAMP	KY
Chant	119000	3307	0	37	6	6618	64.85	45.57	91.37	74.7
Erhu Fiddle	240718	517	0	6	6	1038	53.32	21.05	74.44	35.19
Chinese Zither	167416	991	0	11	6	1986	63.52	40.74	79.63	55.07
Traditional Chinese music	252029	142	0	2	6	288	47.99	26.82	73.75	38.14

Remark: $db_T = 3.84$ dB, $L_T = 2.5$ ms, $S_u = 0.13$ ms and $n = 20$.

Table 2
The 2nd test of Experiment 1.

	Medium length (ms)	Capacity (bit)	Length expansion (ms)		Overhead information (byte)		SNR (dB)		ASNR (dB)	
			DAMP	KY	DAMP	KY	DAMP	KY	DAMP	KY
Chant	119000	5522	0	62	6	11048	64.72	45.37	90.74	73.97
Erhu Fiddle	240718	2566	0	29	6	5136	46.61	20.86	66.78	32.08
Chinese Zither	167416	9181	0	102	6	18366	61.69	40.63	80.77	53.47
Traditional Chinese music	252029	2437	0	28	6	4878	44.82	20.09	68.52	29.45

Remark: $db_T = 8.96$ dB, $L_T = 2.5$ ms, $S_u = 0.13$ ms and $n = 20$.

Table 3
The 3rd test of Experiment 1.

	Medium length (ms)	Capacity (bit)	Length expansion (ms)		Overhead information (byte)		SNR (dB)		ASNR (dB)	
			DAMP	KY	DAMP	KY	DAMP	KY	DAMP	KY
Chant	119000	3307	0	37	6	6618	75.6	45.57	89.06	74.7
Erhu Fiddle	240718	517	0	6	6	1038	60.61	21.05	82.42	35.19
Chinese Zither	167416	991	0	11	6	1986	66.17	40.74	83.36	55.07
Traditional Chinese music	252029	142	0	2	6	288	53.64	26.82	79.32	38.14

Remark: $db_T = 3.84$ dB, $L_T = 2.5$ ms, $S_u = 0.1$ ms and $n = 25$.

Table 4
The 4th test of Experiment 1.

	Medium length (ms)	Capacity (bit)	Length expansion (ms)		Overhead information (byte)		SNR (dB)		ASNR (dB)	
			DAMP	KY	DAMP	KY	DAMP	KY	DAMP	KY
Chant	119000	5522	0	62	6	11048	74.27	45.37	89.12	73.97
Erhu Fiddle	240718	2566	0	29	6	5136	56.86	20.86	79.01	32.08
Chinese Zither	167416	9181	0	102	6	18366	69.2	40.63	85.84	53.47
Traditional Chinese music	252029	2437	0	28	6	4878	53.3	20.09	75.92	29.45

Remark: $db_T = 8.96$ dB, $L_T = 2.5$ ms, $S_u = 0.1$ ms and $n = 25$.

information capacity is increased. On the contrary, seeing that the Kaabneh–Youssef scheme can not provide the function of dynamic adjustment, the length expansion will be increased proportional to the capacity of watermarking information.

4.1.3. The information capacity required for examination

The purpose of this analysis is to evaluate the information capacity required for examination, so as to calculate the necessary storage space. Assume that each vital data is stored with 2 bytes. From Tables 1–4, one can be seen that the proposed scheme only requires the space of 6 bytes on whatever conditions. Nevertheless, the Kaabneh–Youssef scheme needs more space for unfixed data capacity on different conditions. The reason of the above difference is that the proposed scheme only uses three critical values db_T, L_T, and S_u to extract the watermark while their scheme has to keep every mute period length of the original audio file for extracting. To be precise, since the number of mute periods is equal to the watermarking information capacity in this experiment, (i.e., one

Fig. 3. The embedded monochrome BMP image.

Table 5
The results of Experiment 2.

	Medium length (ms)	Capacity (bit)	Length expansion (ms)		Overhead information (byte)		SNR (dB)		ASNR (dB)	
			DAMP	KY	DAMP	KY	DAMP	KY	DAMP	KY
Saxophone	480000	65839	0	732	6	131682	39.1	−6.78	113.89	−7.34
Declaration of Independence	639840	48697	0	732	6	97398	94.85	36.19	100.88	60.96

Remark: db_T = 3.84 dB, L_T = 1 ms, S_u = 0.05 ms and n = 20.

mute period embeds one bit,) we can express the information capacity required for examination with their scheme as Eq. (3).

$$\text{Total bytes} = (\text{watermarking information capacity} \times 2) + 4. \quad (3)$$

Note that the additional 4 bytes of the equation are used to find db_T and L_T values.

4.1.4. The influence on audio quality and imperceptibility

If the watermarking information makes only a slight influence on audio quality, the imperceptibility is considered to be better; in other words, it is more difficult to detect the position or even the existence of watermarking information (Megias et al., 2003). In the subsection, we use Signal-to-noise ratio (SNR) and Average SNR (ASNR) to evaluate the impact on audio quality with our proposed scheme. The SNR value is used to compare the difference between the original signal and the processed one, i.e., the intensity of the noise it produced (Andres, 2002; Uludag & Arslan, 2001). Eq. (4) is the formula to compute SNR value, where N is the number of samples.

$$SNR = 10\log_{10}\left(\frac{\sum_{i=1}^{N} S(i)^2}{\sum_{i=1}^{N}(S(i) - S'(i))^2}\right) \quad (4)$$

It is believed that the larger the value is, the less distortion the processed signal has. An audio file has less distortion also means that its quality is better. Generally speaking, an acceptable SNR value shall be greater than 35 dB (Andres, 2002). Namely, when the SNR value is greater than 35 dB, it is not easy to perceive the existence of watermarking information, i.e., it will be more difficult to tell the difference between signals. The ASNR value applies the sampling number of SNR value to define a specific length as the sampling block, and then computes the SNR value of each block, respectively, to get its mean (Megias et al., 2003). Usually, under the 44.1 kHz sampling frequency, the length is defined to be 4 ms (Megias et al., 2003).

Tables 1–4 showed the results of the first experiment, where DMAP and KY stand for the proposed and the Kaabneh–Youssef schemes, respectively. It is easy to see that our scheme has a better performance. Besides, one can see that with the same threshold values of db_T and L_T, the SNR value is getting higher when the value of S_u is becoming smaller. This is because that when the S_d value is becoming smaller, the scale for the adjustment of mute period length is also getting smaller; therefore, if the S_d value is too large, it might make the SNR value out of the acceptable range.

4.2. Analyses of the second experiment

In the experiment, we use a monochrome BMP image (Fig. 3) of 196 dots in its width and height as the watermarking information to embed it into audio files. The experimental results are demonstrated as Table 5. Since an image file has a larger size and more variable content compared with text-based data, we observe that the length expansion of the Kaabneh–Youssef scheme is significantly increased while that of the proposed one still keeps the same length. Consequently, we can argue that with the Kaabneh–Youssef scheme, the length expansion is proportionally increased with the capacity of watermarking information. However, our scheme dynamically adjusts the length of next mute period according to the variation of current one and hence can minimize the influence on the total audio length when the capacity of watermarking information is increased. As for the SNR values with our proposed scheme, they are still within an acceptable range. In addition, the ASNR values are even over 100 dB.

Clearly, it can be seen that the proposed method also has a better performance in the requirement of imperceptibility.

5. Conclusions

In this paper, we have presented a watermarking method for audio file. By adjusting the length of mute period dynamically, the proposed method can achieve the goal of watermark embedding with little variation of the original work. Experiments showed that our method has a better performance in term of efficiency and fidelity. To conclude the above descriptions and analyses, the merits of our proposed scheme are summarized as follows.

(a) The original audio file is not required for extracting the watermarking information.
(b) Each length of mute periods of the original audio file is also not necessary for extracting the watermarking information.
(c) It only needs three critical values db_T, L_T, and S_u to extract the watermarking information, which benefits to the file management and the communication bandwidth.
(d) The variation of length expansion is negligible.

Appendix A

Notations.

AO original audio file
AO' audio file with watermarking information
ST sampling time, e.g., 0.023 ms
ao_i vibration amplitude of ith sampling value of AO
ao'_i vibration amplitude of ith sampling value of AO'
x number of mute periods
db_T threshold value of vibration amplitude of mute periods, e.g., 2 dB
L_T threshold value of lasting time of mute periods, e.g., 10 ms;
$\text{AMP}(\cdot)$ strength of vibration amplitude
SP set of all mute periods of AO, i.e.,

$$SP = \{sp_i | i \in [1, x], \text{AMP}(sp_i) \leqslant db \text{ and } |sp_i| \geqslant L_T\}$$

SP' set of all mute periods of AO', i.e.,

$$SP' = \{sp'_i | i \in [1, x],\ \text{AMP}(sp'_i) \leqslant db_T \text{ and } |sp'_i| \geqslant L_T\}$$

SP_{min} the minimum mute period of SP, i.e., $SP_{min} = \min(SP)$
n the number of slice, e.g., 10
S_u information examination value satisfying that $S_u = SP_{min}/n$
HD watermarking information, e.g.,

$$\begin{aligned} HD &= 10011001110110 \\ &= \{b_0, b_1, b_2, b_3, \ldots, b_n\} \\ &= \{b_i | i \in [0, n] \text{ and } b_i = [0, 1]\}; \end{aligned}$$

HD' extracted watermarking information
N bit-length of HD
SP' set of all mute periods with the watermarking information
DA cumulative variations of mute period lengths

Algorithm DAMP-E ($\boldsymbol{AO}, \boldsymbol{db_T}, \boldsymbol{L_T}, \boldsymbol{n}, \boldsymbol{HD}$)

Initialization: $x \leftarrow 0$, $DA \leftarrow 0$, $L \leftarrow 0$, $i \leftarrow 0$, $SP \leftarrow 0$
/* L: Length of mute period, i: for index use */
Do Until EOF (AO)
  (a) $i \leftarrow i + 1$
  (b) if $ao_i \leqslant db_T$ then
    (b-1) $L \leftarrow L + ST$
  (c) else
    (c-1) if $L \geqslant L_T$ then
      (c-1-1) $x \leftarrow x + 1$
      (c-1-2) $sp_x \leftarrow L$
      (c-1-3) Add sp_x to SP
    (c-2) $L \leftarrow 0$
END DO
$SP_{min} \leftarrow \min(SP)$
$S_u \leftarrow SP_{min}/n$
For $i \leftarrow 1$ to x
  (a) if $DA < 0$ then
    (a-1) $\alpha \leftarrow sp_i - L_T$
    (a-2) if $\alpha + DA \geqslant 0$ then
      (a-2-1) $sp_i \leftarrow sp_i + DA$
      (a-2-2) $DA = 0$
    (a-3) else
      (a-3-1) $sp_i \leftarrow sp_i + \alpha$
      (a-3-2) $DA \leftarrow \alpha + DA$
  (b) else
    (b-1) $sp_i \leftarrow sp_i + DA$
    (b-2) $DA = 0$
  (c) $A \leftarrow \lfloor sp_i/S_u \rfloor$
  (d) $A \leftarrow A + ((A + HD_{(i-1) mod N}) \bmod 2)$
  (e) $sp'_i \leftarrow A \times S_u$
  (f) if $sp'_i < L_T$ then
    (f-1) $sp'_i \leftarrow sp'_i + 2S_u$
  (g) $DA \leftarrow DA + (sp_i - sp'_i)$
  (h) $sp_i \leftarrow sp'_i$
Next i

Algorithm DAMP-R ($\boldsymbol{AO'}, \boldsymbol{db_T}, \boldsymbol{L_T}, \boldsymbol{S_u}$)

Initialization: $x \leftarrow 0$, $L \leftarrow 0$, $i \leftarrow 0$, $SP' \leftarrow 0$
/* L: Length of mute period, i: for index use */
Do Until EOF (AO')
  (a) $i \leftarrow i + 1$
  (b) if $ao'_i \leqslant db_T$ then
    (b-1) $L \leftarrow L + ST$
  (c) else
    (c-1) if $L \geqslant L_T$ then
      (c-1-1) $x \leftarrow x + 1$
      (c-1-2) $sp'_x \leftarrow L$
      (c-1-3) Add sp'_x to SP'
    (c-2) $L \leftarrow 0$
END DO
For $i \leftarrow 1$ to x
  (a) $C \leftarrow sp_i/S_u$
  (b) $D \leftarrow C \bmod 2$
  (c) $HD'_i \leftarrow D$
Next i

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