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A New Method to Estimate Peak Signal to Noise Ratio for Least Significant Bit Modification Audio Steganography

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ABSTRACT

Audio steganography is implemented based on three main features: capacity, robustness, and imperceptibility, but simultaneously implementing them is still a challenge. Embedding data at the Least Significant Bit (LSB) of the audio sample is one of the most implemented audio steganography methods because the method will give high capacity and imperceptibility. However, LSB has the lowest robustness among all common methods in audio steganography. To cater to this problem, researchers increased the depth of the embedding level from fourth to sixth and eighth LSB level to improve its robustness feature. However, consequently, the imperceptibility feature, which is commonly measured by Peak Signal to Noise Ratio (PSNR), is reduced due to the trade-off between imperceptibility and robustness. Currently, the lack of study on the estimation of the PSNR for audio steganography has caused the early assessment of the imperceptibility-robustness trade-off difficult. Therefore, a method to estimate PSNR, known as PSNR Estimator (PE), is introduced to enable early evaluation of imperceptibility feature for each stego-file produced by the audio steganography, which is important for the utilisation of embedding. The proposed PE estimates the PSNR based on the pattern collected from the embedment at different levels. From the evaluation, the proposed method has 99.9% of accuracy in estimating PSNR values at different levels. In comparison with the Mazdak Method,

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the proposed method performs better in all situations. In conclusion, the proposed PE can be used as a reference for embedding and further reducing the calculation complexity in finding the feasible value to minimise the trade-off between robustness and imperceptibility.

Keywords: Audio steganography, Least Significant Bit, peak-signal-to-noise-ratio estimator, trade-off

INTRODUCTION

This Audio steganography is a method to conceal the secret message by using some method to modify the audio so that only the sender and the intended recipient knows (Alsabhany et al., 2018; Hameed, 2018; Hameed et al., 2019; Jayapandiyan et al., 2020; Sapra, 2016). It exploits Human Auditory System (HAS) to achieve secure communication (Yu et al., 2020). The common audio files used in audio steganography are wave file (.wav) and MPEG-1 Audio Layer III (.mp3) (Sun et al., 2012; Wakiyama et al., 2010).

For any audio steganography method to be successfully implemented, it is important to consider three features: capacity, imperceptibility and robustness (Alsabhany et al., 2020; Amirtharajan & Rayappan, 2013; Hameed, 2018; Zumchak, 2016). First, capacity refers to the amount of secret data embedded inside a cover file (Somani & Madhu, 2015; Srivastava & Rafiq, 2012). Next, the imperceptibility means that the furtive data should not be detected in humans, although there is a difference between cover file and stego-file audio (Somani & Madhu, 2015; Srivastava & Rafiq, 2012). Lastly, robustness refers to the ability of the embedded data to withstand attacks (Somani & Madhu, 2015; Zumchak, 2016). Although audio steganography needs all these features in top conditions simultaneously, there are always trade-offs between all these three features, such as between capacity and robustness (Bhowal et al., 2017; Kumar, 2016), capacity and imperceptibility(Ali et al., 2017; Alsabhany et al., 2019) and lastly, imperceptibility and robustness (Gopalan & Fu, 2015; Xue et al., 2018). The trade-off relationship between audio steganography features is shown in Figure 1. Total disregard for any feature may lead to an unbalanced and impractical audio steganography method (Ali et al., 2017; Gopalan, 2018).

The most common existing audio steganography methods are phase coding, Least Significant Bit (LSB) modification, echo hiding, parity coding, wavelet domain and spread spectrum (Mazdak et al., 2012). This research focuses on the LSB modification because

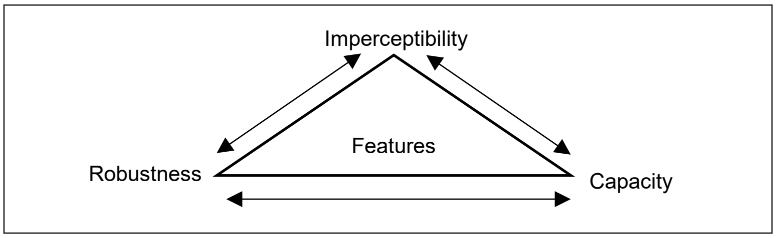

Figure 1. Trade-off relationship among audio steganography features

of its simplicity, flexibility to modification, efficiency, high imperceptibility and capacity (Asad et al., 2011; Djebbar et al., 2011; Tayel et al., 2016; Mazdak et al., 2012). However, although it has numerous advantages, it has low robustness features and is easy to extract (Cvejic & Seppänen, 2005; Kanhe et al., 2015; Meligy et al., 2016). Therefore, researchers proposed to embed the data at a higher level of LSB to increase the robustness features of audio steganography (Ahmed et al., 2010; Priyanka et al., 2012; Cvejic & Seppänen, 2004). However, by doing so, the imperceptibility feature in the LSB method is reduced.

The imperceptibility feature of an audio steganography method is commonly calculated using PSNR. However, to measure the PSNR, a stego-file needs to be produced from the embedding process. In order to find the feasible results that can be used to minimise the trade-off between imperceptibility and robustness feature, the process of embedding the secret data at a different level of LSB and comparing the PSNR value for each stego-file produced is needed. These processes are time-consuming. Therefore, PE is introduced.

The method to estimate the PSNR, also known as PE, will enable early evaluation on imperceptibility feature for each stego-file produced by the audio steganography that can be used as a reference for utilisation of embedding. Additionally, in a real-time application, computational complexity is crucial to ensure an audio steganography implementation (Mazdak et al., 2012). Therefore, PE can avoid repetitive embedding processes in finding the feasible solution for the trade-off, further reducing the computational complexity. Furthermore, we can avoid bad stego-file from being produced, which improves audio steganography efficiency.

The structure of the paper is as follows: the related works are presented in section 2; the proposed method is presented in section 3; the expected results are presented in section 4; and finally, the conclusion and future work are presented in section 5.

RELATED WORK

Most of the existing research on audio steganography targets only one or two features and discards the other. Hence, PSNR calculation is only carried out at the final stage. Therefore, although several advantages can be achieved by estimating the PSNR, only one research has proposed on PSNR estimation in audio steganography. Mazdak et al. (2012) proposed a PSNR estimation method based on linear interpolation formula. The method uses PSNR value and bit per sample (BPS) rate on existing stego-file to estimate PSNR value of new stego-file that embed different bps rate. This method tries to tackle the trade-off between imperceptibility and capacity features of audio steganography.

PE is also used in image steganography for similar purposes. For example, Li et al. (2014) had proposed PSNR estimation based on Mean Squared Error (MSE) value. It is used to compare the level of distortion between the original signal and the stego-file (Chadha et al., 2013). Suppose $x = \{x_i \mid i = 1,2,3,..,N\}$ is the original signal and

$y = \{y_i \mid i = 1,2,3,..,N\}$ is the stego-file signal and where N is the number of signal samples and x_i and y_i are the value of i^th samples in x and y, respectively. The MSE formula is calculated using Equation 1:

$$MSE(x,y) = \frac{1}{N}\sum_{1}^{N}(x_i - y_i)^2 \quad (1)$$

This estimation is also calculated based on bit per sample. However, it is mentioned that the method works best when the BPS rate is less than four because of the size of bit depth in the image sample that is considered small when compared to the audio. This estimation method reduces the expansion of the stego-file needed for the shadow image. The main focus of this method is to improve the imperceptibility feature of image steganography instead of tackling the existing trade-off.

Based on the previous research, it is shown that there is a lack of research conducted for estimating the PSNR value in audio steganography. In addition, the lack of a PSNR estimator focuses on determining the PSNR value to solve the trade-off. The only PSNR estimator in audio steganography is focused on determining the efficiency of a steganography technique for the trade-off between capacity and imperceptibility. Therefore, this research tries to provide a new method for estimating the PSNR value at the different levels of LSB of audio steganography based on PSNR patterns defined from embedding at a different level of LSB to cater to different types of trade-off, which is between imperceptibility and robustness.

METHODOLOGY

This paper proposes a method to estimate the PSNR value for audio stego-file based on the patterns observed from the PSNR values obtained from embedding at a different level of LSB. A series of experiments are conducted to find patterns in PSNR values. The first experiment was conducted on finding PSNR value at the lowest level of LSB for different sizes of embedded data and the number of audio samples. The second experiment was conducted on finding PSNR values at a different level of LSB for different sizes of embedded data and the number of audio samples. Finally, the new method for estimating PSNR value is proposed based on the patterns from the PSNR values obtained at a different level of LSB embedding.

PSNR of One Bit per Sample at the First LSB

The objective of this experiment is to observe the similarity of the PSNR value at the lowest level of LSB. The PSNR values between all the stego-file produced should be almost identical to ensure the validity of the pattern. Ten different cover audios ranging from one to ten seconds with 16-bit depth and 44.1kHz mono are selected from various speech and music .wav audio files to ensure the diversity of the experiment's samples. The ratio of the size of data embedded to number of audio sample is approximately one to two. For each cover audio, a customised size of data is embedded at the first level of LSB of cover audio samples, and the PSNR values for each stego-file produced are recorded. Cover audio name, a total of cover audio samples, size of data embedded and obtained PSNR are tabulated in Table 1.

Table 1 shows that the PSNR for all tested cover audio is between a range of 96.32 dB and 96.34 dB, which indicates that PSNR values are almost the same at the lowest level of LSB.

Table 1
Obtained PSNR for one bit per sample at first level LSB

Cover Audio	*Cover Audio Samples*	*Size of Data (bit)*	*PSNR*
Music 1.wav	44100	22050	96.328
Music 2.wav	132300	66150	96.317
Music 3.wav	220500	110250	96.331
Music 4.wav	352800	176400	96.328
Music 5.wav	441000	220500	96.336
Speech 1.wav	44100	22050	96.292
Speech 2.wav	132300	66150	96.343
Speech 3.wav	220500	110250	96.318
Speech 4.wav	352800	176400	96.323
Speech 5.wav	441000	220500	96.324

PSNR of One Bit per Sample at Different Level LSB

The objective of this experiment is to find the pattern among the PSNR value produced from embedding at a different level of LSB. Therefore, the data is embedded at a different level of LSB. The second, fourth, sixth, seventh and eighth levels of LSB are selected. This experiment is implemented by embedding the data at a different level of LSB of cover audio sample accordingly. Then, the PSNR value for each stego-file is recorded. Cover audio names and obtained PSNR at different LSB levels are tabulated in Table 2.

Based on Table 2, the stego-file produced shows the identical value at all embedding levels. In addition, significant and identical decrement for PSNR value from the lowest level of LSB to the highest level of LSB is shown in all audios. Therefore, it can be concluded that there is a pattern in the difference of PSNR value that can be used to estimate the PSNR at a different level.

Table 2
Obtained PSNR of one bit per sample at different level LSB

Cover Audio	PSNR Obtained					
	1st level	*2nd level*	*4th level*	*6th level*	*7th level*	*8th level*
Music 1.wav	96.328	90.330	78.256	66.215	60.203	54.186
Music 2.wav	96.317	90.289	78.253	66.221	60.216	54.183
Music 3.wav	96.331	90.306	78.243	66.226	60.192	54.171
Music 4.wav	96.328	90.293	78.263	66.253	60.208	54.195
Music 5.wav	96.336	90.299	78.274	66.218	60.226	54.177
Speech 1.wav	96.292	90.315	78.260	66.214	60.150	54.193
Speech 2.wav	96.343	90.322	78.264	66.210	60.191	54.210
Speech 3.wav	96.318	90.289	78.277	66.233	60.231	54.182
Speech 4.wav	96.323	90.288	78.271	66.229	60.205	54.190
Speech 5.wav	96.324	90.308	78.269	66.246	60.205	54.213

Method on Estimating PSNR Value based on Pattern

In order to estimate the PSNR value for a different level of LSB, the differences between the PSNR value from Table 2 are used as a basis. The PSNR difference at different levels of LSB is shown in Table 3.

Table 3
Obtained PSNR difference at different level of LSB

Cover Audio	PSNR Difference at Different Level				
	1st & 2nd level	*2nd & 4th level*	*4th & 6th level*	*6th & 7th level*	*7th & 8th level*
Music 1.wav	5.998	12.074	12.041	6.012	6.017
Music 2.wav	6.028	12.036	12.032	6.005	6.033
Music 3.wav	6.025	12.063	12.017	6.034	6.021
Music 4.wav	6.035	12.03	12.01	6.045	6.013
Music 5.wav	6.037	12.025	12.056	5.992	6.049
Speech 1.wav	5.977	12.055	12.046	6.064	5.957
Speech 2.wav	6.021	12.058	12.054	6.019	5.981
Speech 3.wav	6.029	12.012	12.044	6.002	6.049
Speech 4.wav	6.035	12.017	12.042	6.024	6.015
Speech 5.wav	6.016	12.039	12.023	6.041	5.992

Table 3 shows the obtained PSNR values for ten audio files at different embedding levels. Since the differences are almost identical, ranging from 5.977 to 6.049 at one different level and ranging from 12.01 to 12.074 at two different levels, the average can create a constant in developing a formula for PSNR estimation.

In order to collect the average of PSNR differences between each level, the value of the difference at two levels of embedding should be divided by two to get the average difference in PSNR value at one difference level. Therefore, a new table is tabulated to display all the differences. Table 4 shows the difference in the PSNR values at all different levels of LSB.

Table 4
Obtained PSNR difference at all level of LSB

Cover Audio	PSNR Difference at Different Level						
	1st & 2nd level	*2nd & 3rd level*	*3rd & 4th level*	*4th & 5th level*	*5th & 6th level*	*6th & 7th level*	*7th & 8th level*
Music 1.wav	5.998	6.037	6.037	6.021	6.021	6.012	6.017
Music 2.wav	6.028	6.018	6.018	6.016	6.016	6.005	6.033
Music 3.wav	6.025	6.032	6.032	6.009	6.009	6.034	6.021
Music 4.wav	6.035	6.015	6.015	6.005	6.005	6.045	6.013
Music 5.wav	6.037	6.013	6.013	6.028	6.028	5.992	6.049
Speech 1.wav	5.977	6.028	6.028	6.023	6.023	6.064	5.957
Speech 2.wav	6.021	6.029	6.029	6.027	6.027	6.019	5.981
Speech 3.wav	6.029	6.006	6.006	6.022	6.022	6.002	6.049
Speech 4.wav	6.035	6.009	6.009	6.021	6.021	6.024	6.015
Speech 5.wav	6.016	6.02	6.02	6.012	6.012	6.041	5.992

After calculating the difference value at each level, the average difference for PSNR value between each level is 6.02. Hence, a novel formula is proposed, which is based on the average differences retrieved from the pattern shown. The formula is as in Equation 2:

$$y = x - (6.02 * (l_n - l_x)) \quad (2)$$

where y is the expected PSNR at a different level, while x is the initial PSNR value at any level, while 6.02 is a constant calculated from the average differences between one upper level and one lower level. Finally, l_n is the new embedding LSB level, while l_x is the initial LSB level. The new formula can estimate the PSNR value for stego-file at a different level of LSB embedding. Figure 2 shows the flowchart of the proposed estimation method.

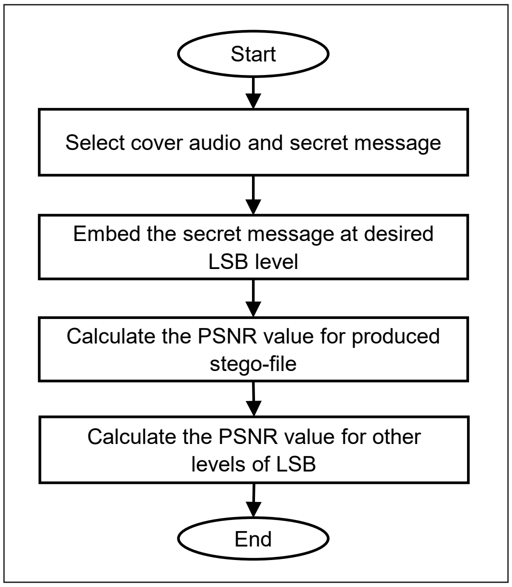

Figure 2. Proposed estimation method flowchart

The estimation process starts by selecting the cover audio and secret message that needs to be hidden. Next, the secret message is embedded into one of the least significant bit levels of the cover audio sample, and modified cover audio is compiled into the stego-file. The stego-file is then evaluated by calculating its PSNR value. Finally, the PSNR value for other levels of LSB can be measured using Equation 2.

EVALUATION AND DISCUSSION

An accuracy test is carried out to evaluate the proposed method. The average accuracy for the method is calculated using the Equation 3:

$$a = 100\% - \left(\frac{d}{v}\right) * 100\% \quad (3)$$

where a is the average accuracy, d is the average absolute difference between estimated PSNR and actual PSNR, and v is the average of actual PSNR value.

All covers for this evaluation are collected from www.freesound.org. They have 44.1KHz for sample rate, mono channel, wav file format and has 16-bit depth. In addition, speech, music, and silence type audio ranged, which has 1, 3, 5, 8, and 10 seconds are used to give a better view on the capabilities of the method. The number of secret message bits embedded in the cover for this test is at around 50% from the audio sample.

This test compares the estimation of PSNR value for fifteen (15) stego-file at different embedding levels against the actual PSNR value of this stego-file. Furthermore, it estimates two different levels of embedding, which are at the third level of LSB, and the seventh level of LSB, for a better view of the method's performance. Therefore, the proposed Equation 2 is used, and the result for the estimation stego-file PSNR from third level embedding is recorded in Table 5, while the result for the estimation stego-file PSNR from seventh level embedding is recorded in Table 6.

Based on Table 5, the average difference between the estimation and the actual result is 0.0184. For the individual difference, the differences vary between one to the others because of the difference of cover audio files and secret data used. Using different cover audio files and secret data will generate different numbers of bits flipping, leading to the error during the embedding process. Furthermore, if the size of the secret message is big, more modifications will be made to the cover audio sample bit; hence higher error is introduced. In this round, this method can estimate the PSNR value with 99.978% accuracy.

Based on Table 6, the average difference between the estimation and the actual result is 0.0118. The difference is quite similar to the result from Table 5, and both values are considered small. In this round, this method can estimate the PSNR value with 99.98% accuracy.

Based on the result from Tables 5 and 6, this method can estimate the PSNR value with high accuracy. Furthermore, the result shows that the difference between estimation and the actual value is less than 0.1 at different levels.

Table 5
Comparison between estimation and actual result of stego-file from 3rd level embedding

Audio	Obtained PSNR for 4bps	Estimated PSNR for 3bps	Actual PSNR for 3bps	Absolute difference
Music 1.wav	78.3062	84.3262	84.3459	0.020
Music 2.wav	78.2817	84.3017	84.2983	0.003
Music 3.wav	78.2326	84.2526	84.2813	0.029
Music 4.wav	78.277	84.297	84.2893	0.008
Music 5.wav	78.2686	84.2886	84.3032	0.015
Speech 1.wav	78.2513	84.2713	84.2699	0.001
Speech 2.wav	78.2926	84.3126	84.2652	0.047
Speech 3.wav	78.3005	84.3205	84.2828	0.038
Speech 4.wav	78.2882	84.3082	84.2986	0.010
Speech 5.wav	78.2872	84.3072	84.2963	0.011
Silence 1.wav	78.2864	84.3064	84.3034	0.003
Silence 2.wav	78.3011	84.3211	84.3081	0.013
Silence 3.wav	78.3102	84.3302	84.3067	0.023
Silence 4.wav	78.3133	84.3333	84.3009	0.032
Silence 5.wav	78.3012	84.3212	84.2983	0.023
		Average	84.29654667	0.0184
	Accuracy of the proposed method to the average actual result			99.978

Table 6
Comparison between estimation and actual result of stego-file from 7th level embedding

Audio	Obtained PSNR at 5th Level	Estimated PSNR at 7th Level	Actual PSNR at 7th Level	Absolute difference
Music 1.wav	72.2872	60.2472	60.1891	0.0581
Music 2.wav	72.2685	60.2285	60.2065	0.0220
Music 3.wav	72.2662	60.2262	60.2098	0.0164
Music 4.wav	72.2396	60.1996	60.2001	0.0005
Music 5.wav	72.2522	60.2122	60.2034	0.0088
Speech 1.wav	72.2784	60.2384	60.2687	0.0303
Speech 2.wav	72.2568	60.2168	60.2297	0.0129
Speech 3.wav	72.254	60.214	60.2186	0.0046
Speech 4.wav	72.2477	60.2077	60.211	0.0033
Speech 5.wav	72.2573	60.2173	60.2317	0.0144
Silence 1.wav	72.2784	60.2384	60.2372	0.0012
Silence 2.wav	72.3043	60.2643	60.2631	0.0012
Silence 3.wav	72.2952	60.2552	60.254	0.0012
Silence 4.wav	72.2981	60.2581	60.2569	0.0012
Silence 5.wav	72.2829	60.2429	60.2417	0.0012
		Average	60.2281	0.0118
	Accuracy of the proposed method to the average actual result			99.98

A comparison was made between the proposed method and Mazdak Method (Mazdak et al., 2012). Mazdak Method focuses on estimating PSNR at different bps rates to cater for the trade-off between capacity and imperceptibility. On the other hand, the proposed method focuses on estimating the PSNR value for one bit per sample at a different level to cater for the trade-off between robustness and imperceptibility. Both methods have different objectives, but the accuracy percentage between them can still be compared.

In order to make a comparison, the same audio used in the previous test is used. PSNR values for 3bps and 7bps embedding are estimated using Mazdak Method and compared against the actual PSNR value. The formulation used for Mazdak Method to give a brief idea is presented in Equation 4:

$$y = y_a + (x - x_a)\frac{y_b - y_a}{x_b - x_a} \quad (4)$$

where x is a given bps rate, and y is its PSNR. Hence, x_a represents the bps rate for a, x_b represents the bps rate for b, y_a represents the PSNR of embedding with *a* bps rate, and y_b represents the PSNR of embedding with b bps rate.

PSNR values from embedding with 4bps and 2bps of 15 audio files are recorded in Table 7. Equation 4 was used to estimate the PSNR value for 3bps. The estimated PSNR value for 3bps, actual PSNR value for 3bps and absolute difference is recorded in Table 7.

PSNR values from embedding with 5bps and 8bps of 15 audio files are recorded in Table 8. The same Equation 4 was used to calculate PSNR to estimate the PSNR value for 7bps. The estimated PSNR value for 7bps, actual PSNR value for 7bps and the absolute difference is recorded in Table 8.

Based on Table 7, the average absolute difference between the estimation and the actual result is 0.2953. Therefore, based on Equation 3, Mazdak Method can estimate the PSNR value with 99.646%.

Based on Table 8, the average absolute difference between the estimation and the actual result is 0.8844, and the estimation accuracy is 98.474%. The differences are higher than the estimation of PSNR value from embedding 3bps secret message, which indicates that the Mazdak method has lower accuracy when estimating PSNR for the embedding at higher bps.

Although Mazdak Method can estimate the PSNR value when embedding with different bps rates, the accuracy is reduced when estimating a higher bps rate. The proposed method obtained higher accuracy than Mazdak Method because the patterns for whole cases were collected and studied, producing stable estimation, which can be maintained around 99.9.

Table 7
Comparison between estimation and actual result based on Mazdak Method (3bps)

Audio	Obtained PSNR for 4bps	Obtained PSNR for 2bps	Estimated PSNR for 3bps	Actual PSNR for 3bps	Absolute difference
Music 1.wav	77.6152	89.6416	83.6284	83.1304	0.498
Music 2.wav	77.7262	89.6785	83.70235	83.3395	0.363
Music 3.wav	77.7314	89.7031	83.71725	83.3806	0.337
Music 4.wav	77.7226	89.7036	83.7131	83.3746	0.338
Music 5.wav	77.7247	89.7238	83.72425	83.3948	0.329
Speech 1.wav	77.8145	89.7295	83.772	83.4211	0.351
Speech 2.wav	77.8175	89.7161	83.7668	83.3902	0.377
Speech 3.wav	77.8026	89.7277	83.76515	83.3936	0.372
Speech 4.wav	77.8228	89.7263	83.77455	83.4121	0.362
Speech 5.wav	77.8317	89.7342	83.78295	83.2441	0.539
Silence 1.wav	76.5157	89.7555	83.1356	83.2157	0.080
Silence 2.wav	76.5209	89.6912	83.10605	83.255	0.149
Silence 3.wav	76.5293	89.6974	83.11335	83.242	0.129
Silence 4.wav	76.5236	89.7243	83.12395	83.229	0.105
Silence 5.wav	76.5381	89.7478	83.14295	83.244	0.101
			Average	83.3111	0.2953
				Accuracy of the proposed method to the average actual result	99.646

Table 8
Comparison between estimation and actual result based on Mazdak Method (7bps)

Audio	Obtained PSNR for 5bps	Obtained PSNR for 8bps	Estimated PSNR for 7bps	Actual PSNR for 7bps	Absolute difference
Music 1.wav	71.0445	54.6277	60.09996667	59.0499	1.050067
Music 2.wav	71.2037	54.6757	60.18503333	59.1703	1.014733
Music 3.wav	71.2392	54.7271	60.23113333	59.2143	1.016833
Music 4.wav	71.2929	54.7314	60.2519	59.2527	0.9992
Music 5.wav	71.2967	54.7486	60.26463333	59.2424	1.022233
Speech 1.wav	71.2006	53.1268	59.1514	58.1282	1.0232
Speech 2.wav	71.1503	52.7786	58.9025	57.9722	0.9303
Speech 3.wav	71.2226	53.2252	59.22433333	58.4405	0.783833
Speech 4.wav	71.1999	53.2412	59.22743333	58.3946	0.832833
Speech 5.wav	71.2124	53.1347	59.1606	58.3311	0.8295
Silence 1.wav	69.1936	51.1402	57.158	56.3932	0.7648
Silence 2.wav	69.1907	51.1533	57.16576667	56.4313	0.734467
Silence 3.wav	69.1883	51.1632	57.17156667	56.4236	0.747967
Silence 4.wav	69.1746	51.1607	57.16533333	56.4134	0.751933
Silence 5.wav	69.1861	51.1646	57.17176667	56.4071	0.764667
			Average	57.9510	0.8844
				Accuracy of the proposed method to the average actual result	98.474

CONCLUSION

This paper proposes a new method to estimate the PSNR value of any LSB embedding level to cater to the trade-off between imperceptibility and robustness. PSNR values' pattern from embedding at a different level of LSB, which affect the robustness features, can be used to estimate the PSNR specifically for the imperceptibility feature of audio steganography. The estimated PSNR value generated based on the new method has an average of 99.9% accuracy compared to the actual embedding result at a different level of LSB throughout different embedding levels. The proposed method obtained higher accuracy when compared to Mazdak Method and only needed one actual PSNR value compared to Mazdak Method, which needs two actual PSNR values to operate. However, the focus of the proposed method is only on LSB modification. Hence, it is not suitable and accurate to implement the frequency domain in audio steganography.

To conclude, this method can be used as a utilisation tool to refrain from the repetition of embedding processes in finding the feasible solution to cater for the trade-off problem between imperceptibility and robustness features and further reducing the computational complexity of unnecessary repetitive embedding processes. Furthermore, the efficiency of an audio steganography method can be improved as any bad cover audio can be avoided from being produced. Future work that can be considered includes creating a steganography method based on this new estimation method to obtain a method with balanced features in terms of imperceptibility and robustness.

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