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Optimized Multirate Wideband Speech Steganography for Improving Embedding Capacity Compared with Neighbor-Index-Division Codebook Division Algorithm

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Abstract
Aim: *The main motive of this study is to perform Adaptive Multi Rate Wideband (AMR-WB) Speech Steganography in network security to produce the stego speech with less loss of quality while increasing embedding capacities.* ***Materials and Methods:*** *TIMIT Acoustic-Phonetic Continuous Speech Corpus dataset consists of about 16000 speech samples out of which 1000 samples are taken and 80% pretest power for analyzing the speech steganography. AMR-WB Speech steganography is performed by Diameter Neighbor codebook partition algorithm (Group 1) and Neighbor Index Division codebook division algorithm (Group 2).* ***Results:*** *The AMR-WB speech steganography using DN codebook partition obtained average quality rate of 2.8893 and NID codebook division algorithm obtained average quality rate of 2.4196 in the range of 300bps embedding capacity.* ***Conclusion:*** *The outcomes of this study proves that the decrease in quality in NID is twice more than the DN based steganography while increasing the embedding capacities.*

Key-words: Innovative Speech Steganography, Network Security, Embedding Capacity, Diameter Neighbor Codebook Partition, Neighbor Index Division Codebook Division Algorithm.

1. Introduction

Speech steganography is the method of embedding the secret messages in the recommended audio files by using several merging techniques and sending the file to receivers end for extraction of data (Bender et al. 1996). In the present day scenario the usage of audio based communication is increasing rapidly as the population and technology is growing. The secure transmission of data has become one of the major issues. However in network security the encryption and decryption have been mostly adapted techniques to prevent the data loss but attackers may have ability to access the ciphered data. This is where steganography comes into picture. Several implementations on audio steganography have been reported in the past few years. The main application of the AMR-WB speech steganography is in mobile handsets and covert communications where the confidential data is transmitted from sender to receiver end.

This research has explored several paper publications and research articles in which around 18 papers were found in IEEE Xplore based on audio steganography and several embedding techniques. Out of which the most cited articles are taken for this research work. Gruh et al in (Gruhl, Lu, and Bender 1996) proposed a speech steganographic method of echo hiding by the synthetic resonances in the form of closely spaced echoes. Gopalan (K. Gopalan 2003) presented a method of embedding a covert audio message into a cover file by altering one bit in each of the cover utterance samples. Gopalan et al. (Kaliappan Gopalan et al. 2003) provided two methods of secret message embedding by modifying the phase or amplitude of perceptually masked or significant regions of a host. A direct sequence spread-spectrum watermarking process with strong robustness against common audio editing procedures was proposed in (Kirovski and Malvar 2003). Based on segmental SNR analysis (Gruhl, Lu, and Bender 1996) of changing the encoded bits, Liu et al. (L. Liu et al. 2008) has taken the least important bits to embed secret messages in G.729 speech. In (Xu and Yang 2009), a simple and effective steganographic approach, which may be applied to 5.3 Kbps G.723.1 speech, was presented on analyzing the redundancy of code parameters, and augmented identity matrix was utilized to lower the distortion of cover audio. Similarly, by calculating speech quality on each encoded bit out of 244 bits using perceptual evaluation of audio quality (PESQ) criterion, a data hiding method to embedding data in enhanced full rate (EFR) compressed audio bitstream is proposed in (Shahbazi, Rezaie, and Shahbazi 2010). In addition, Nishimura (Nishimura 2009) proposed three methods of securing data in the pitch delay data of the AMR speech. Based on complementary neighbor vertices codebook division algorithm (CNV), Xiao et al. (Xiao, Huang, and Tang 2008) proposed an approach to hiding information in compressed speech by using quantization index modulation (QIM).

Previously our team has a rich experience in working on various research projects across multiple disciplines (Sathish and Karthick 2020; Varghese, Ramesh, and Veeraiyan 2019; S. R. Samuel, Acharya, and Rao 2020; Venu, Raju, and Subramani 2019; M. S. Samuel et al. 2019; Venu,

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Subramani, and Raju 2019; Mehta et al. 2019; Sharma et al. 2019; Malli Sureshbabu et al. 2019; Krishnaswamy et al. 2020; Muthukrishnan et al. 2020; Gheena and Ezhilarasan 2019; Vignesh et al. 2019; Ke et al. 2019; Vijayakumar Jain et al. 2019; Jose, Ajitha, and Subbaiyan 2020). Now the growing trend in this area motivated us to pursue this project.

Based on the literature survey, the most of the PESQ scores for increasing embedding capacities in various coding modes are less. It was expertised in this domain and has chosen the above research problem and addressed it by means of using the Diameter neighbor codebook partition algorithm. The proposed method is performed to produce the least loss of speech quality while the embedding capacities are increasing by using AMR-WB speech steganography.

2. Materials and Methods

The experimental study setup for the proposed system is held in Saveetha University. Two groups are considered for this study. First group is the DN codebook partition algorithm and the second group is the NID codebook division algorithm (J. Liu et al. 2016). The 4 average samples each for two groups and a total of 8 samples are considered for statistical analysis in the SPSS tool with 95% confidence and 80% pretest power.

Audio Database

The dataset TIMIT Acoustic-Phonetic Continuous Speech Corpus is downloaded from a public domain Linguistic Data Consortium https://catalog.ldc.upenn.edu/LDC93S1. This dataset contains broadband recordings of 630 speakers of eight major dialects of American english, each reading 10 phonetically rich sentences. The total of a 1000 samples are taken from this database. All audio files are modified into AMR-WB format using standard codec and used for speech steganography.

The statistical analysis is conducted using IBM SPSS V26.0 tool. SPSS is an application package for Social Sciences used for calculating statistical calculations such as mean, standard deviation, significance and also used to plot the graphs. The independent variables are speech size and speech type. Dependent variable is embedding capacity. In SPSS 10 samples are considered for statistical analysis and the group ids for DN and NID are taken as 1 and 2.

AMR-WB Codec

The AMR-WB speech codec is standardized by 3rd Generation Partnership Project and used as the standard G.722.2 by ITU-T in 2002 where the improved speech quality of audio files is obtained by using AMR-WB codec. At the bit rates between 6.6 kbit/s to 23.85 kbit/s, the incoming audio signal is divided into a 20ms frame length with 16 kHz rate. This frame contains a linear prediction analysis (LPA) and the LP coefficients are modified in to immittance spectrum pairs (ISP) coefficients. The ISP coefficients are considered and then modified into frequency domain (ISF) for quantization. Except for mode 0 (6.6 kbit/s), the ISF coefficients are quantized using two-stage vector quantization with split-by-2 in first stage and split-by-5 in the second stage.128 codewords are present in second, third codebooks, and the ISF indices of the codewords in these codebooks are used to embed secret messages in the audio files. At the receiver end the decode is used to parse the transmitted indices received from bitstream and then decoded to obtain the code parameters for every transmitted frame, such as the ISP vector, the 4 fractional pitch lags, the 4 LTP filtering parameters, the 4 innovative code vectors, and the 4 sets of vector quantized pitch and innovative gains. By analysing these received ISF indices, which may have been changed because of secret message embedding, the receiver can retrieve and extract the embedded secret message.

Neighbor Index Division Algorithm

The codewords in a codebook can be divided into sub codebooks based on their indices instead of the Euclidean distance because these codewords are close together. This process involves following steps:

1. An integer k is selected for embedding capacity and label the ith codeword with digit $(i-1)$ mod k, respectively.
2. All the codewords with same label into a sub codebook are collected and k different subcodebooks are produced. The binary secret message is modified into k-ary digits denoted by m ($m \in \{0, 1, \ldots, k-1\}$).
3. The codeword connected to the quantization index belonged to the subcodebook where label differs with the k-ary digit m to be embedded, then this index modified with that of the closest codeword in the corresponding subcodebook m.

This speech steganography using NID is an information hiding process based on neighbor-index codebook partition, where the number of subcode books k embedding capacities can be modified with closest codeword. 34% of the neighbor-index codewords pairs regarded as the pairs of neighbor-vertex codewords. The mean distance between neighbor-index codewords is apparently higher than that of neighbor-vertex codewords. Therefore, the total amount of distortion produced in NID-based steganography may be a little large.

Codebook Partition Method

Secret messages can be merged into an AMR-WB speech file using the DN codebook partition. The secret message is extracted with zero errors from the stego audio file. At the same time, the decoded speech with less loss of quality is received. The proposed method contains the diameter-neighbor codebook partition algorithm (DN) with the embedding and extraction processes carried out.

The codebook is divided into different clusters by applying the codebook partition method where codebook is regarded as multidimensional code vectors, here the codewords can be replaced with each other with zero perceptible distortion.

B - The original codebook with Nb codewords,

C - Nc codewords Wt (t = 1, 2, . . . , Nc).

The centroid is defined as follows:

$$G(i) = 1/Nc \sum_{t=1}^{Nc} Wt\,(i) \quad (1)$$

here $G(i)$ and $Wt(i)$ are represented as the ith components of G and Wt.

The centroid G is taken as the corresponding cluster C; hence, the cluster C is taken as a vector. The resemblance in two clusters $C1$ and $C2$ can be calculated by the Euclidean distance between them:

$$D(C1, C2) = \sqrt{\sum_{i=1}^{n} (G1(i) - G2(i)^{2}} \quad (2)$$

$G1$ and $G2$ - geometric centers of the two clusters $C1$ and $C2$.

n- dimension of a codeword;

$G1(i)$ and $G2(i)$ - ith components of $G1$ and $G2$.

S - cluster set.

Euclidean distance - Dm of all cluster pairs in the cluster set S, followed by:

$$(Cp, Cq) \leq Dm\ \forall p, q = 1, 2, \ldots, |S| \quad (3)$$

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$|S|$ - The number of clusters within the cluster set S.

The cluster pair having higher Euclidean distance Dm are taken as diameter cluster pair, and are denoted by ($Cd1$, $Cd2$). The neighbor of a cluster C in S is represented by (C, S):

$$(C, N(C, S)) \leq (C, Cp) \ \forall p = 1, 2, \ldots, |S| \qquad (4)$$

Embedding Process

The indices regarding the codewords in the codebook are first produced by changing the adaptive multirate wideband speech in the proposed system. These ISF indices are employed to merge secret messages into the speech using a codebook partition algorithm. In General, the codewords in the cluster are interchanged within each other. Ia can be replaced by the other codewords indices within the same cluster based on the message to be embedded based on the size of the particular cluster message. Steps for embedding are listed as follows:

Step 1: The cluster C should be obtained in cluster set S.

Step 2: The total number of secret bits $n = \lfloor \log 2N \rfloor$.

N- Number of codewords in cluster set C.

Step 3: Take not embedded bits as m.

Ia is replaced with Ib.

Step 4: Redo the above 3 steps until all the secret bits are embedded in speech.

Extracting Procedure

Once the receiver obtains the encoded AMR-WB stego speech, the message is extracted. The Message extraction process includes below steps:

Step 1: Cluster set C in S is obtained.

Step 2: The total number of secret bits is computed by $n = \lfloor \log 2N \rfloor$.

Step 3: Then$n$ bits are added to the secret message bit sequence.

Step 4: Redo the above 3 steps until all the secret bits are extracted.

Statistical Analysis

SPSS Version 21 software tool was used for statistical analysis. Independent sample T test was conducted for accuracy. Standard deviation, standard mean errors were calculated using the SPSS Software tool.

3. Results

The MOS-LQO Values based on the embedding rate 300bps for five average samples of mean quality rates for both group1-DN and group2-NID are recorded and it is observed that the MOS-LQO values are better in DN rather than NID.

The embedding capacities of both the AMR speech steganography methods DN and NID are compared and recorded. The quality of parsed speech is also taken in consideration and the difference is analysed. The statistical analysis of the observations proved that the proposed AMR-WB speech steganography has good audio quality with improved embedding capacities.

Table 1- MOS-LQO Values for Three Embedding Rates and Four Rate Modes 12.65kbit/s, 15.85kbit/s, 19.85kbit/s, 23.85kbit/s. The Average MOS-LQO Values in the Proposed System are 3.216, 3.164, 3.04 in 23.85kbit/s Rate Mode

Embedding rate	**Methods**	**Rate Mode (kbit/s)** 12.65	**Rate Mode (kbit/s)** 15.85	**Rate Mode (kbit/s)** 19.85	**Rate Mode (kbit/s)** 23.85
100 bps	PROPOSED NID	2.864 2.750	3.010 2.895	3.136 3.020	3.216 3.091
200 bps	PROPOSED NID	2.736 2.601	3.010 2.736	3.084 2.875	3.164 2.921
300 bps	PROPOSED NID	2.699 2.284	2.841 2.386	2.971 2.475	3.046 2.533

The speech quality is evaluated by using perceptual evaluation of speech quality (PESQ) process. The raw PESQ score can be converted into mean opinion score-listening quality objective (MOS-LQO), which is used for evaluating wideband speech. The normal range of MOS-LQO score is 1.017 to 4.549. The greater the score, better the quality. Therefore MOS-LQO is used in this study. The below given Table 1 shows the average MOS-LQO values in 4 different rate modes of stego speeches for three embedding capacities.

Table 2- Mean and Standard Deviation Values of MOS-LQO Scores in Three Different Embedding Rates 100bps, 200bps, 300bps for DN and NID are 3.0572, 3.0025, 2.8893

Groups	100bps	200bps	300bps
NID			
Mean	2.9390	2.7832	**2.4196**
Standard Deviation	0.14980	0.14473	0.10870
DN			
Mean	3.0572	3.0025	**2.8893**
Standard Deviation	0.15434	0.15621	0.15251
Total			
Mean	2.9981	2.8929	2.6544
Standard Deviation	0.15434	0.18212	0.27943

Fig. 1- Embedding and Extracting Procedure in Proposed System

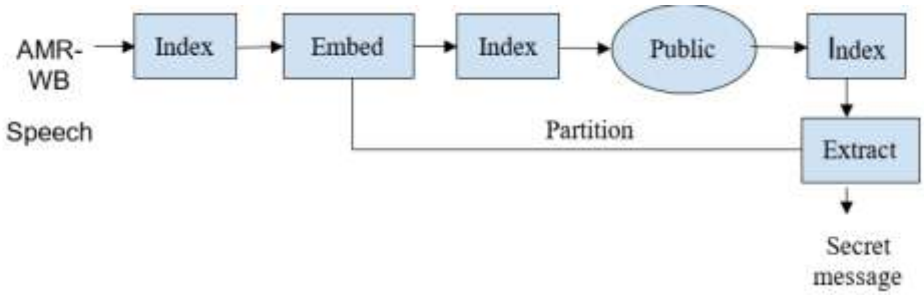
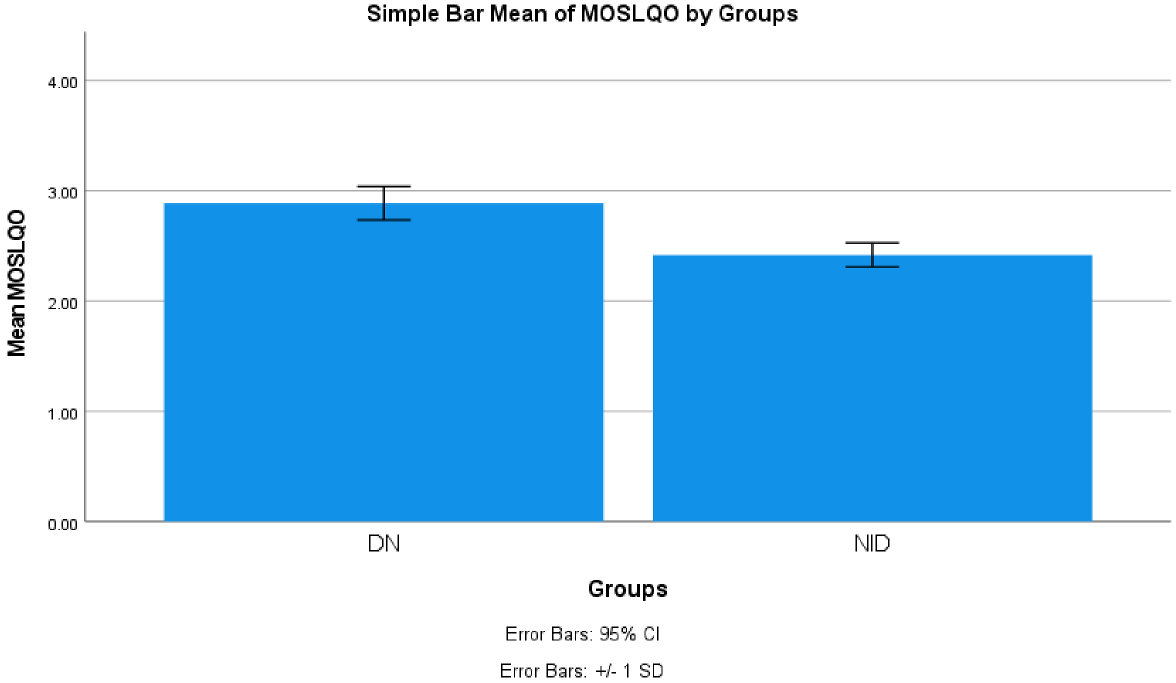


Table 3- Independent Samples Test for Calculating the T-test for Equality Means with Mean Difference of 0.46975 and Standard Error Difference of 0.9364 by taking the 95% Confidence Interval of difference and Significant Difference Less than 0.05

MOS-LQO	**Levene's Test for Equality of Variances**					**T-test for Equality of Means**		**95% Confidence interval of the difference**	
	F	Sig	t	df	Sig (2)	Mean Differen ce	Std error difference	Lower	Upper
Equal variances assumed	.733	.425	5.017	6	.002	.46975	.09364	.24062	.69888
Equal Variances not assumed			5.017	5.423	.003	.46975	.09364	.23458	.70492

The flow chart for the embedding and extracting procedures is illustrated in Fig. 1, here firstly the secret message is embedded into the cover speech and partition algorithm is applied and then the secret message is extracted from stego speech using the extracting procedure. From the given graph in Fig. 2 it was observed that the quality rate of stego speech is higher for the DN codebook partition algorithm with 2.8894 rather than the NID codebook division algorithm with 2.4196. The significant difference is less than 0.05 in independent samples tested in the SPSS tool. The average quality rates of proposed and existing systems are given in the table 1 for three different embedding rates 100bps, 200bps, 300bps.The average MOS-LQO values in the proposed system are 3.216, 3.164, 3.04 in 23.85kbit/s rate mode. In Table 2 the mean and standard deviation values are illustrated such as 2.8894 for the DN algorithm and 2.8894 for the NID algorithm. In table 3 the Independent Samples Test for calculating the T-test for equality means with mean difference of 0.46975 and standard error difference of 0.9364 by taking the 95% confidence interval of difference and significant difference less than 0.05 are illustrated using the SPSS tool. The mean value of quality rates for the DN algorithm appears to be greater when compared with the NID algorithm.

Fig. 2- The above given Bar Chart Represents the Comparison of MOS-LQO Values based on the Embedding Rate - 300bps for Five Average Samples of Mean Quality Rates for Group1-DN and Group2-NID. X-axis: DN and NID Algorithms are taken as Two Groups. Y-axis: Mean MOS-LQO Values for Effective Quality Prediction with ± 1 SD



4. Discussion

In this study it is observed that the DN algorithm produces a higher quality (2.8893) stego speech than the NID algorithm (2.4196). Many methods and techniques for embedding messages have been implemented in the past few years. Gopalan et al (Kaliappan Gopalan et al. 2003) proposed audio steganography for embedding messages using amplitude or phase modification.

(Q. Liu, Sung, and Qiao 2011) was noticed as close paper and steganalysis of QIM steganography in low bit-rate speech signals where the loss of quality of speech is less. An approach to hide information in the low bitrates speech spectrum called CNV algorithm producing a quality

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rate of 2.01 is proposed in (Xiao, Huang, and Tang 2008). An information hiding technique using G.729 bitstream is proposed in (L. Liu et al. 2008).

Our institution is passionate about high quality evidence based research and has excelled in various fields (Vijayashree Priyadharsini 2019; Ezhilarasan, Apoorva, and Ashok Vardhan 2019; Ramesh et al. 2018; Mathew et al. 2020; Sridharan et al. 2019; Pc, Marimuthu, and Devadoss 2018; Ramadurai et al. 2019). We hope this study adds to this rich legacy.

The limitation of this study is, the quality of the speech is less when the embedding rates are lesser and comparatively the same as the NID algorithm. If the speech quality is better in low embedding rates the accuracy could have been gradually increased. In future the AMR-WB speech steganography can be carried out by using different algorithms to produce better stego speech quality in the lesser embedding capacities too. However this work can be enhanced by using quantization and several embedding techniques.

5. Conclusion

The experimental results proved that the speech quality for improving embedding capacities in group 1 appears to be more effective than the existing group 2 i.e. NID method. AMR-WB Speech steganography using DN Codebook partition produced the speech quality mean rates of 3.8%, 7% and 15% appears to be greater than the speech quality rates in NID Codebook division algorithm when the embedding rates are 100bps, 200bps, 300bps.

Declarations

Conflict of Interests

No conflict of interest in this manuscript.

Authors Contributions

Author AMK was involved in data collection, data analysis, manuscript writing. Author BMG was involved in conceptualization, data validation, and critical review of manuscript.

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