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FORMING AND DETECTION OF DIGITAL WATERMARKS IN THE SYSTEM FOR AUTOMATIC IDENTIFICATION OF VHF TRANSMISSIONS

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Forming and detection algorithms for digital watermarks are designed for automatic identification of VHF radiotelephone transmissions in the maritime and aeronautical mobile services. An audible insensitivity and interference resistance of embedded digital data are provided by means of OFDM technology jointly with normalized distortions distribution and data packet detection by the hash-function. Experiments were carried out on the base of ship's radio station RT-2048 Sailor and USB ADC-DAC module of type E14-140M L-CARD in the off-line processing regime in MatLab medium.

Issue Statement

Presently in the Very High Frequency (VHF) bands of maritime (156 - 174) MHz and aeronautical (118 - 136) MHz mobile services an analog modulations (frequency/phase and amplitude accordingly) are used for radiotelephone transmissions. Identification of the transmitted vessel is executed by means of voice naming of call sign or digital identification of the transmitting station. Because of some conditions the voice identification might be absent at all, transmitted with delay or interpreted incorrectly in the receiver. It is obvious that absence or misunderstood voice identification in the radiotelephony seriously impacts on general safety in maritime and aeronautical transport.

One of the solutions eliminating a "human factor" in the task of addressed telephony in the mobile radio communication is implementation of automatic identification on the base of so called Digital Watermarking (DWM) technology. DWM with reference to VHF radiotelephony means digital information embedding directly into audio signal and transmission this information in the standard radiotelephone channel. This method doesn't need replacement of legacy radio installation, allocation of any additional frequency-time channel recourses and radiotelephone procedures replacement.

Besides the main task solution of reliable identification the combined digital information and voice signal transmission provides: 1) sending an identification data to another information systems; 2) monitoring of radio transmissions to violators identification; 3) utilization the covered information transmission in the special applications, for example, against terrorist threats.

Review of Studies and Publications

General problems of digital steganography and DWM design considered in monographs [1, 2]. One of the methods for DWM embedding that takes into account carrier (or host) signal is Quantization Index Modulation (QIM) [3]. QIM is based on scalar quantization of host samples (or its transformation) and transmitting of theirs quantized values. However QIM is sensitive to amplitude scale transformation.

In the paper [4] Improved Spread Spectrum (ISS) algorithm is proposed that is insensitive to amplitude distortions, but is subjected to Intersymbol Interference (ISI).

In the article [5] the algorithms for generating DWM in amplitudes of narrowband Hilbert transformed signals are studied for DWM robustness enhancement in the band limited channel with ISI influence.

Aim of the Paper

The present article is aimed to design and investigation of forming and detection audio DWM algorithms which are robust to amplitude distortions and ISI. The designed system is based on the novel approaches in audio DWM technique: 1) application of OFDM technology, 2) normalized allocation of audio signal distortions, 3) processing and detecting the whole DWM data packet on the base of hash function calculation.

DWM Forming

ISI is caused by the transceiver frequency band limitation and multipass nature of radio wave propagation. In the radiotelephony voice signal transmitting is realized in the frequency band 300 - 3000 Hz. Amplitude versus frequency function (AFF) in this band is greatly ununiformed because of capacitors and inductors presence in the low frequency circuits. Multipass wave propagation causes the fast frequency dependent distortions of the received signal. Therefore two different by its physics nature reasons result in the same linear or intersymbol interferences.

To reduce ISI impact the OFDM (Orthogonal Frequency Division Multiplexing) is proposed for DWM forming. OFDM is widely used in the modern communication systems of various purposes and grounded on the division of spectrum frequency band to series of narrowband subchannels with orthogonal subcarrier frequencies. Herewith "fast" data flow is split to several "slow" flows, which are transmitted independently in the each band subchannel. Within each subchannel AFF can be set constant and phase versus frequency response is linear, therefore ISI influence in every subchannel may be ignored. The total rate of information transferring along all subchannels remains invariable. Technically OFDM is based on direct and invers Discrete Fourier Transform (DFT) application.

One-channel DWM embedding algorithm is characterized as follows. Stegosignal, that is, signal with embedded DWM is forming according formula:

$$\mathbf{s} = \mathbf{x} + \mathbf{w}(\tilde{x}, m), \tag{1}$$

where $\mathbf{s}, \mathbf{x}, \mathbf{w}$ are vectors of length L, standing for stegosignal, host signal and DWM sequences correspondingly; $\tilde{x} = (\mathbf{x}, \mathbf{u})$ is scalar product of host signal and a certain pseudorandom sequence (PRS) $\mathbf{u}$: $u_i = \{\pm 1\}$, $m = \{\pm 1\}$ is embedded bit.

Amplitudes of frequency DFT coefficients with equal indexes are used in the capacity of host signal.

Coordinates of vector $\mathbf{w}$ in (1) are calculated according formula:

$$w_i = \tilde{w} \left(|x_i| / \|\mathbf{x}\|_p \right)^p u_i, \tag{2}$$

where $\|\mathbf{x}\|_p = \left(\sum_{i=1}^{L} |x_i|^p \right)^{1/p}$ denotes p-norm of vector $\mathbf{x}$, and value $\tilde{w}$ is defined as:

$$\tilde{w} = \begin{cases} 0, & m\tilde{x} \geq \rho, \quad (3\text{ a}) \\ m\rho - \tilde{x}, & m\tilde{x} < \rho, \quad (3\text{ б}) \end{cases}$$

In the formula (3) ρ stands for threshold that specifies DWM robustness against interferences.

Implication of algorithm (3) is cleared as follows. If $m\tilde{x} \geq \rho$ (case (a)), then any distortions into the signal to transmite DWM bit is not necessary at all. The required bit will be naturally detected in the receiver. In (b) case it is necessary to introduce a certain distortions that would correct scalar product $\tilde{s} = (\mathbf{s}, \mathbf{u})$ to one of values, depending from DWM bit:

$$\tilde{s} = \begin{cases} \rho, & m = 1, \\ -\rho, & m = -1. \end{cases} \tag{4}$$

Optimal choosing for norm parameter p in the formula (2) must be stated by the human perception to distortions introduced into an audio signal. In general case $p > 0$. When $p = 1$ correction value $\tilde{w}$ is distributed proportionally to vector $\mathbf{x}$ amplitudes:

$$w_i = \tilde{w} \frac{|x_i|}{\|\mathbf{x}\|_1} u_i. \tag{5}$$

When $p \to 0$ $\tilde{w}$ is distributed uniformly to all samples x_i. In particularly for such case the ISS algorithm is presented in paper [4]. For uniform distribution formula (2) becomes:

$$w_i = \frac{\tilde{w}}{L} u_i.$$

Within the signal class with $\tilde{w} = const$ uniform allocation minimizes mean squared distortions, however human auditory perception because of masking effect from great amplitudes and decreasing noise occurrence in the pauses testifies in favor of p selection in the range 0,5 … 1.

Received vector equals:

$$\mathbf{y} = \mathbf{x} + \mathbf{w} + \mathbf{n},$$

where $\mathbf{n}$ denotes the noise vector.

In the receiver scalar product $\tilde{y} = (\mathbf{y}, \mathbf{u})$ is evaluated, that is equivalently to correlation determination between received and reference signals. Estimation of the detected bit is produced by sign of the scalar product:

$$\hat{m} = sign(\mathbf{y}, \mathbf{u}).$$

In matrix representation for multichannel realization algorithm (1) may be written as:

$$\mathbf{S} = \mathbf{X} + \mathbf{W}(\tilde{\mathbf{X}}, \mathbf{M}),$$

where $\mathbf{X}, \mathbf{W}$ denote $(B \times L)$ dimension matrixes for amplitude coefficient of the host signal and DWM respectively in the frequency domain, $\tilde{\mathbf{X}}$ is the vector $(B \times 1)$ of scalar products, $\mathbf{M}$ is the vector $(B \times 1)$ of embedded identification digital data.

Elements of upper part in the matrix of complex coefficients $\dot{S}_b$ are determined by the next way:

$$\dot{S}_b = \begin{cases} X_b, & b = 0, B+1, ..., N/2, \\ S_b \exp(j\phi_b), & b = 1, 2, ..., B, \end{cases} \tag{6}$$

where ϕ_b are phases of coefficients X_b.

To provide real type of samples in the time domain it is necessary construct lower part of matrix $\mathbf{S}$ as complex conjugation of the upper part:

$$\dot{S}_{b+N/2} = \dot{S}_{N/2-b}, b = 1, 2, ..., N/2 - 1. \tag{7}$$

For notation simplicity indexation of corresponding columns $l = 1, 2, ..., L$ in relations (6) and (7) is omitted.

DWM forming is illustrated by scheme in fig. 1 for values N =8, L=5, B=2.

detected if calculated hash function under the received data coincides with the received hash data.

Such method of DWM location doesn't call for additional synchronizing sequence transferring, data starting marker and checking sum. All these appropriate problems are solved by means of the whole packet sequence processing and comparison of the received and transmitted hash function. Influence of synchronization inaccuracy problem to detection reliability is also excluded. At that detection reliability is defined by the hash function length. Practically hash function length of 15 bits is sufficient. For this case probability of false location comes to 2^{-15}.

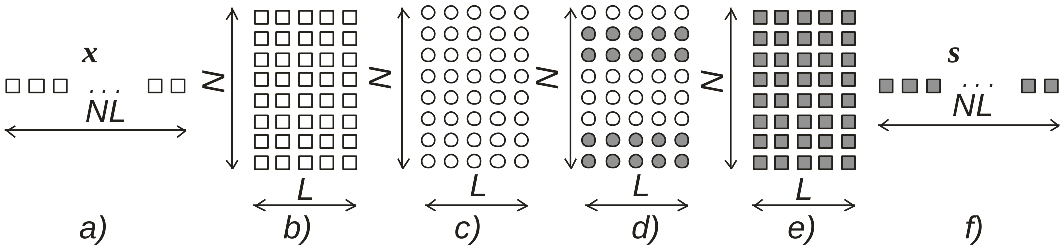

Fig. 1. DWM forming

Processed block length for these values constitutes 40 samples for two DWM bits. Sequence of host signal samples in the time domain is drawn by squares, a). Block of 40 samples is formatted by columns into matrix of 8×5 dimension, b). Next, frequency coefficients of DFT are calculated by matrix column. The frequency coefficients are depicted by circles, c). An upper row corresponds to constant term in DFT composition.

After that amplitude modification is evaluated for frequency coefficients by above presented algorithms according to relations (1) - (5), d). Modified by the amplitude frequency coefficients are marked with grey. In the fig. 1 amplitudes of first and second harmonics (the second and third rows respectively) are subjected to modification. Rows 7 and 8 are complex conjugated to rows 3 and 2 correspondingly. The next step invers DFT (IDFT) is executed also by matrix column. After IDFT stegosignal samples are obtained, that are marked out by gray too, e). Matrix 8×5 is read off by column forming stegosignal samples, f).

Detection of DWM and Synchronization

Detection of DWM is based on correlation sum (scalar product) evaluation between DFT amplitudes of received samples sequence and reference PRS. For correct detection it is necessary to synchronize correlator's operation with the input sequence. Let us resolve issue of synchronization and detection jointly by means of the whole sample sequence processing, which corresponds to one DWM packet. It is supposed that DWM packet presents a DWM data sequence proper and a certain hash function calculated under the DWM data. In the receiver DWM packet is considered as located and properly detected if calculated hash function under the received data coincides with the received hash data.

Charges for this approach are locating delay on duration of one packet in the receiver and rather large-scale calculations, which has to be made with the sampling rate.

Simulation and Experimental Results

Experiments were carried out in the practical VHF radio channel on the frequency 156.850 MHz (maritime channel 17) using two sets of ship born radio station RT-2048 Sailor and USB -module of analog-to-digital converter (ADC) and digit-to-analog converter (DAC) of type E14-140M L-CARD. Methodic of experiment carrying out was the following. DWM data block of length B=15 bit performed by the designed algorithm was repeatedly introduced into a voice fragment using MatLab environment. Sampling frequency F_s =8 kHz, subchannel bandwidth Δf =125 Hz under DFT dimension N=64. Then processed file was passed through the DAC to VHF radio input, emitted on the air, received by another VHF radio set and via ADC stored in audio file. After that the received file was processed in MatLab medium to DWM detection. Therefore the transmission signal was performed in the practical radio channel using off-line mode software processing.

Experimental results under signal-to-noise ratio in radio channel 15 dB are given in table 1, assuming the next notations: *WSR* stands for Watermark-to-Signal Ratio, *L* is PRS length, *R* is DWM data rate.

All DWM blocks placed in voice length from 27000 samples were detected steadily correctly.

Table 1

Experimental Results

WSR, dB	-16,5	-14,6	-12,1
L	31	15	7
R, bit/sec	60	125	268

Transmission rate of the covered information is defined by the formula:

$$R = \frac{B\,F_s}{N\,L}.$$

Simulation in MatLab medium showed DWM robustness against nonlinear signal "clipping" distortions up to level 0.5.

Conclusions

For providing audio DWM robustness against intersymbol interference in the problem of automatic identification of VHF radiotelephone transmission in the maritime radio communication it is proposed OFDM application jointly with known improved spread spectrum (ISS) algorithm. OFDM - ISS algorithm for DWM embedding into analog signal provides DWM robustness against intersymbol interference, nonlinear distortions and additive noise under distortion power due to embedded DWM below intrinsic power lever in the radio channel.

Auditory imperceptibility of DWM is obtained by allocation of its energy in the carrier signal frequency-time plane and appropriate parameter *p* for signal norm setting. The possibility of flexible selection of parameters N, L, B and ρ provides compromise settlement of designing DWM system characteristic problem.

Location and detection of DWM are produced by processing of the whole sample packet on the base of hash functions comparing. Such approach allows managing without transferring synchronizing sequence, marker and checking sum at all.

Practical implementation of the identification system on the base of DWM may be executed without replacement of legacy VHF marine radio installations. Regular VHF transceiver should be supplemented with the electronic chip which contains identification data and might be mounted directly into the receiver. Also mini display should be switched to the transceiver audio output to display identification data of the transmitting station.

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