Contents

Research Articles

Research on the Structure and Signal Transmission of Rotary Piezoelectric Dynamometer
Zhenyuan Jia, Yongyan Shang, Zongjin Ren, Yifei Gao and Shengnan Gao............................ 1

Piezoelectric Sensor of Control Surface Hinge Moment
Zongjin Ren, Shengnan Gao, Zhenyuan Jia, Yongyan Shang and Yifei Gao......................... 11

Research Algorithm on Building Intelligent Transportation System based on RFID Technology
Chuanqi Chen ............................................................................................................................ 18

Using Displacement Sensor to Determine the Fracture Toughness of PMMA Bone Cement
Yongzhi Xu, Youzhi Wang ........................................................................................................ 27

Study on the Applications of Fiber Bragg Grating and Wireless Network Technologies in Telemetry System of Atmospheric Precipitation
Han Bing, Tan Dongjie, Li Liangliang, Liu Jianping ................................................................ 33

Lü Tao, Zhu Qing-Xin, Zhu Yu-Yu ......................................................................................... 41

A Case Study of Event Detection Performance Measure in WSNs Using Gini Index
Luhutyit Peter Damuut, Dongbing Gu ...................................................................................... 51

Fault Diagnosis of Tool Wear Based on Weak Feature Extraction and GA-B-spline Network
Weiqing Cao, Pan Fu, Genhou Xu .......................................................................................... 60

The Research Abort Concept Restructuring of the Sensor Semantic Networks
Guanwei ..................................................................................................................................... 68

Coordinating Reasoning Method for Semantic Sensor Networks
Shi Yun Ping .............................................................................................................................. 76

A Novel Intelligent Transportation Control Supported by Wireless Sensor Network
Zhe Qian, Jianqi Liu. .................................................................................................................. 84

Research on the Special Railway Intelligence Transportation Hierarchy and System Integration Methodology
Meng-Jie Wang, Xi-Fu Wang, Wen-Ying Zhang, Xue Feng ...................................................... 89

Application of a Heterogeneous Wireless Framework for Radiation Monitoring in Nuclear Power Plant
Gu Danying ............................................................................................................................... 98
Acoustic Emission Signal Analysis of Aluminum Alloy Fatigue Crack
Wenxue Qian, Xiaowei Yin, Liyang Xie...................................................................................... 105

A New Ultra-lightweight Authentication Protocol for Low Cost RFID Tags
Xin Wang, Qingxuan Jia, Xin Gao, Peng Chen, Bing Zhao....................................................... 110

AGC Design in Frequency Modulation System for Voice Communication via Underwater Acoustic Channel
Cheng En, Chen Sheng-Li, Li Ye, Ke Fu-Yuan, Yuan Fei............................................................. 116

Joint Source-Channel Coding for Underwater Image Transmission
Chen Hua-Bin, Chen Wei-Ling, Li Ye, Cheng En, Yuan Fei.......................................................... 122

Study on the Applications of Cross-Layer Information Fusion in Target Recognition
Xing Liu, Shoushan Jiang ........................................................................................................... 129

A Simple Tree Detector Using Laser and Camera Fusion
D. Wang, J. H. Liu, J. L. Wang, T. Li.......................................................................................... 137

Simulation and Analysis of T-Junction Microchannel
Kainat Nabi, Rida Rafi, Muhammad Waseem Ashraf, Shahzadi Takyaba, Zahoor Ahmad, Muhammad Imran, Faran Baig and Nitin Afzulpurkar............................................................. 146

Mass Flow Measurement of Fluids by a Helically Coiled Tube
Tian Zhou, Zhiqiang Sun, Zhenying Dong, Saiwei Li, Jiemin Zhou............................................. 152

Comparative Creep Evaluation between the Use of ISO 376 and OIML R60 for Silicon Load Cell Characterization
Ebtisam H. Hasan, Rolf Kumme, Günther Haucke and Sascha Mäuselein .................................... 158

Yuriy Bobalo, Zenoviy Kolodiy, Bohdan Stadnyk, Svyatoslav Yatsyshyn .................................. 164

Application of Mixed Programming in the Simulation of Lorenz Chaotic System’s Dynamics Characteristics Based on Labview and Matlab
Peng Zhou, Gang Xu, Liang Chen .............................................................................................. 169

A Nanostructure with Dual-Band Plasmonic Resonance and Its Sensing Application
Zongheng Yuan, Jing Huan, Xiaonan Li and Dasen Ren............................................................. 174

A Glucose Sensor Based on Glucose Oxidase Immobilized by Electrospinning Nanofibrous Polymer Membranes Modified with Carbon Nanotubes
You Wang, Hui Xu, Zhengang Wang, Ruifen Hu, Zhiyuan Luo, Zhikang Xu, Guang Li............. 180

The Platform Architecture and Key Technology of Cloud Service that Support Wisdom City Management
Liang Xiao ....................................................................................................................................... 186

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International Frequency Sensor Association (IFSA).
Digital Sensors and Sensor Systems: Practical Design

Sergey Y. Yurish

The goal of this book is to help the practitioners achieve the best metrological and technical performances of digital sensors and sensor systems at low cost, and significantly to reduce time-to-market. It should be also useful for students, lecturers and professors to provide a solid background of the novel concepts and design approach.

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- Practical orientation.
- Dozens examples of various complete sensors and sensor systems for physical and chemical, electrical and non-electrical values.
- Detailed description of technology driven and costing alternative to the ADC - frequency (time-) to digital conversion.

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Non-Dispersive Infrared Gas Measurement

Jacob Y. Wong, Roy L. Anderson

Written by experts in the field, the Non-Dispersive Infrared Gas Measurement begins with a brief survey of various gas measurement techniques and continues with fundamental aspects and cutting-edge progress in NDIR gas sensors in their historical development.

- It addresses various fields, including:
  - Interactive and non-interactive gas sensors
  - Non-dispersive infrared gas sensors' components
  - Single- and Double beam designs
  - Historical background and today's of NDIR gas measurements

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Joint Source-Channel Coding for Underwater Image Transmission

1 CHEN Hua-Bin, 1 CHEN Wei-Ling, 2 Li Ye, 1 CHENG En, * YUAN Fei
1 Key Laboratory of Underwater Acoustic Communication and Marine Information Technology of the Ministry of Education (Xiamen University), Xiamen, 361005, P. R. China
2 Key Laboratory of Computer Network of Shandong Province, Shandong Computer Science Center, Jinan, 250014, P. R. China
* Tel.: 086-0592-2580143
* E-mail: yuanfei@xmu.edu.cn

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Abstract: Underwater acoustic (UWA) channel is a complex time-, space- and frequency-variant channel. So to realize the high efficiency and real-time transmission of image with great data quantity, it will refer to both source coding and channel coding. In underwater acoustic channel, the Joint Source and Channel Coding (JSCC) get better performance than separated coding. To aim at the image transmission in UWA communication system, this paper presents joint source and channel coding approach, putting forth the technology of joint source and channel coding in image transmission in the underwater acoustic channel. And it is an active attempt that the joint source and channel coding combines with OFDM technology to insure image transmission with high quality in underwater acoustic channel. Studies also show that the method can get better balance between bit error rate and code length, and the image can get better anti-noise property.

Keywords: Image transmission, Underwater acoustic, Joint source-channel coding.

1. Introduction

The use of acoustic wave as message carrier to transmit in a complex time-space and frequency-variant and multipath transmission underwater acoustic channel, is currently the only effective means to achieve underwater wireless communication optional. To complete image transmission which contains a great amount of data in underwater acoustic channel, effective source coding and channel coding is indispensable. In occasion that separation best hypothesis of separation theorem is impossible, balance the source coding bit rate and channel coding rate’s influence to distortion, a kind of Joint Source-Channel Coding to distribute appropriate resources in both source coding and channel coding by a joint strategy in order to make the communication system to be more optimal is getting more and more widespread attention in the communications sector [1].

In this paper, making use of Turbo code’s characteristic of being suitable for the different code rate, we do different error correction protection according to the level of its importance for the reconstructed image whose original image data compressed by SPECK algorithm based on the wavelet transform. This source-based optimization of channel coding takes full advantage of characteristic that Source encoded data stream is in order of importance, and improve the shortage that SPECK algorithm is very sensitive to the bit error. In order to verify the performance of this Joint Source-Channel Coding method.
Coding’s unequal error protection channel coding. This paper introduces a BSC and White Gaussian noise channel model, verifying the performance of joint coding in the above two kinds of model.

2. Joint Source-channel Coding Schemes

The Joint Source-Channel Coding based on SPECK compression coding and Turbo code that is proposed in this paper belong to channel coding based on the source optimization. Its principle is to optimize the distribution of redundant bit or the emission energy in different information bits. In order to get better transmission quality, the more important source data will be distributed more bits (or more emission energy), and the data that is less important will be distributed less bits to obtain a minimum end-to-end distortion [2-4]. The concrete realization of Joint Source-Channel Coding scheme will be described in the following sections, and the principle block diagram of JSCC combined with OFDM is shown as Fig. 1.

![Fig. 1. The principle block diagram of JSCC combined with OFDM.](image)

2.1. SPECK Compression Code

SPECK code is a kind of image coding scheme based on wavelet transform, including initialization, sort, refine and quantization four steps. The wavelet transform using wavelet transform that is constructed by lifting scheme includes the following three steps: split, forecast and update, the core of it is representing it with a more compact form according to some correlation between the data. SPECK code makes the low-frequency information of image concentrating in the upper left corner, and using set partitioning to encode the important information priority [5-7]. It makes important information of image is concentrated in front of the code stream, so that when doing channel encoding, it can be so easy to encode the important information and unimportant information separately.

The steps of SPECK coding algorithm includes: Initialization: In this step we divide the image coefficients matrix that after being processed by wavelet transform into two sets and initialize the threshold and the important coefficients list (LSP) and unimportant coefficient list (LIS); Sorting Pass: This step includes ProcessS(S) and ProcessI(I), in ProcessS(S), we sort the LIS and judge the importance of the sets of LIS, and in ProcessI(I), we judge the importance of the remaining blocks and split; Refinement Pass: We output some specific bits in this step; the last step is Quantization Step. The flow chart of SPECK coding is shown as Fig. 2.

![Fig. 2. The flow chart of SPECK coding.](image)
2.2. Turbo Code

Turbo codes can achieve a better balance between the decoding complexity and bit rate, using low bit rate to do channel encode for important information, and using high bit rate for unimportant information [8]. As for decoding, bit streams having different bit rates should correspond different iteration times in order to reduce the bit error ratio of important information as much as possible and improve the rate of decoding, at last to achieve a better balance of the error rate and the decoding speed [9].

Turbo Code encoder comprises two feedback systematic convolutional (RSC) encoder connected in parallel by an interleaver. Encoded parity bits going through puncturing array, thereby generating a code word of different bit rates [10]. The structure diagram of Turbo code encoder is shown as Fig. 3. Turbo decoder uses a feedback structure, decoding in an iterative manner, while the use of iterative decode is exactly one of underlying reason of why Turbo code can have good performance, it improves the decoding performance by exchanging the soft information of component decoder. The decoding algorithm introduced in this paper is SOVA algorithm, it is generally connected into parallel cascade form, it uses the later bits of information to improve the credibility of the verdict earlier, it can be divided into following steps, the structure diagram of Turbo code decoder is shown as Fig. 4: Calculated path metrics and measurement; Updated reliability metrics; Subtracting the inner information and get outer information value required by the next step.

![Fig. 3. The structure diagram of Turbo code encoder.](image)

![Fig. 4. The structure diagram of Turbo code decoder of SOVA algorithm.](image)

2.3. Joint Source-Channel Coding Realization

Joint Source-Channel Coding principle block diagram is shown as Fig. 5. Its realization is as follows: Wavelet transform: In this paper, lifting scheme is used to do three-level wavelet transform for image. SPECK code: In order to facilitate the procedures for the processing of the wavelet coefficients, the coefficients matrix after wavelet transform is stretched into a one-dimensional array in accordance with the Z-shaped; LISi list records the location of the collection in LIS list (the collection list of unimportant coefficients), LISj list records the size of LIS collection, LSP (the collection list of important coefficients) list records the locations of elements. Then according to threshold value T, scanning the wavelet coefficients one by one from the lowest sub-band. The length of important information should be designed. This length can be decided by the size of the lowest-frequency information after wavelet transform, the size of the high frequency part of information that changes greatly like information representing the edge of image and the size of sequence header. In this paper, the first 1/4 part of the total frame is set as the important information. The selection of the
component encoder: Turbo code used PCCC structure is selected in this paper, the structure of two component encoder (RSC1 and RSC2) is the same, the RSC encoder of (17, 15) structure is used. The random interleaver is used, the code elements are interleaved after a set of random numbers being pretreated. According to the length of important information, first coding the important information that is in the front of the data stream by code rate of 1/3 in parallel convolution way, and coding the unimportant information by code rate of 1/2, then according to puncturing matrix \( P = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \) to puncture. The coding scheme in this paper is aim at underwater acoustic channel (UAC), the conditions of UAC is bad, but it’s the only effective means of optional underwater wireless communication. The decoding of Turbo code uses SOVA iterative decoding, important information after coding by code rate of 1/3 uses the iterative number of 6, as for unimportant information, the number is 4.

![Fig. 5. The principle block diagram of JSCC.](image)

3. Introduction of Channel Model and Method of Image Analysis

Channel is an essential part of any communication system, and the discussion in this paper mainly based on UAC. UAC has numbers of unfavorable factors like high ambient noise, narrow bandwidth, low useful carrier frequency, large transmission delay and so on. It can be one of the most difficult wireless communication channels. The simulation experiments in this paper using two analog channels: white Gaussian noise channel and Binary Symmetric Channel [11].

3.1. White Gaussian Noise Channel

Gaussian channel often refers to the weighted white Gaussian noise (AWGN) channel. In such noise assumption as in the entire channel bandwidth, the power spectral density is a constant, and the amplitude found Gaussian probability distribution, i.e. the so-called white noise. Ideal white noise is not present, but if the uniform distributed frequency range of the noise power spectrum is greater than actual bandwidth of the system, then this noise can be regarded as white noise. Gaussian channel is of great significance for evaluating the upper bound of the performance of a system. In this paper, additive white noise is discussed, which is present in dependent of information signal, and interferes with the information signal in a superimposed form.

3.2. Binary Symmetric Channel

Binary Symmetric Channel is a discrete channel. Its input and output are both this two symbols: 0 and 1, transmits 0 and receive 1 or transmits 1 and receive 0, which both have the same probability. So called channel is symmetrical. The conditional error probability represented by \( p \). Binary symmetric channel transition probability is shown in Fig. 6. The reason to choose such a simple channel like BSC is that it meets the lowest error protection requirements of transmitting any source information in a physical channel, in which a relatively simple environment can help us better understanding the problem.

![Fig. 6. Binary symmetric channel transition probability.](image)
3.3. Image Quality Measure Standard

PSNR, the traditional objective evaluation method based on the statistical properties, is the difference in mathematical statistics. It’s a measure of image that pays attention to rebuilding, or how similar the reconstructed image to the original one. \( I(x, y) \) represents the original image, \( I'(x, y) \) represents distorted image, \( M \times N \) is the size of image, \( m \) is the maximum value of a pixel can be achieved. The expression of PSNR is described as Eq. (1).

\[
\text{PSNR} = 10 \log_{10} \frac{m^2}{\frac{1}{MN} \sum_{i,j} [I(x,y) - I'(x,y)]^2}
\]  

(1)

4. The Results of Joint Source-Channel Coding and Analysis

4.1. BSC Channel

In this paper, the simulation is done in an 8 bit’s Lena picture whose size is 256 \( \times \) 256. The lifting scheme of wavelet transform is used. Transform number is three, and compression ratio is 14:1. The code stream after SPECK coding is divided into 20 frames. Turbo code uses RSC (17, 15) to do separated source-channel equal error protection channel coding and joint source-channel unequal error protection channel coding for experimental image. In binary symmetric analog channel, code rate of 1/2 and iterative decoding time of 4 are used for EEP coding. As for the UEP proposed in this paper, the code rate of the first 5 frames (important information) are 1/3, and the iteration is 4, while the other frames use the code rate of 1/2, and the iteration is 2. When BER is \( 10^{-3}, 5 \times 10^{-3}, 10^{-2}, \) and \( 5 \times 10^{-2} \), doing experiment repeatedly to get average PSNR value, the results is in Table 1.

Through the experiment, we decide that when the PSNR value of reconstructed image is lower than 15 dB, the image is unrecognizable (Fig. 7 (e): EEP BER=\( 5 \times 10^{-2}, \) PSNR=14.9041), and when the PSNR value of reconstructed image is 29.1182 dB, the image is error-free restored (Fig. 7(b): UEP BER= \( 10^{-2}, \) PSNR=29.1184). During these two level of pictures, there’re Fig. 7(c) (EEP, BER=\( 10^{-2}, \) PSNR=22.8346) and Fig. 7(d) (UEP, BER= \( 5 \times 10^{-2}, \) PSNR=22.5134). While Fig. 7(a) is the Initial ‘Lena’. As the result, in case of high BER (BER>\( 5 \times 10^{-3} \)), the performance of UEP is better than EEP, but is not obvious. In the following section, further simulation will be done in white Gaussian noise channel.

| Table 1. Comparison of EEP and UEP under different channel BER. |
|------------------|------------------|------------------|------------------|------------------|
| **Type/BER**     | \( 10^{-3} \)    | \( 5 \times 10^{-3} \) | \( 10^{-2} \)    | \( 5 \times 10^{-2} \) |
| EEP              | 29.1182          | 29.1182          | 22.8345         | 14.9041          |
| UEP              | 29.1182          | 29.1182          | 29.2284         | 22.5134          |

![Fig. 7. EEP vs. UEP (for Lena).](image-url)
4.2. White Gaussian Noise Analog Channel

The experiment was divided into the following three groups. In group one the SNR is 2.0 dB, experimenting for many times, and the experiment condition is EEP with code rate of 1/2 and decoding iterations of 6. In group two the SNR is 2.0 dB, experimenting for many times, the experiment condition is UEP with code rate for important information (first five frames) of 1/3 and decoding iterations of 6, code rate for unimportant information of 1/2, and decoding iterations of 4. In group three the SNR is from 0.5 dB to 3.0 dB, the experiment condition is EEP and UEP. After groups of experiments of above settings, we choose some groups of results representative in this paper to analyze the impact of different source and channel coding scheme for image transmission rebuild. Ex1 and Ex2 taken EEP scheme, and Ex3 taken UEP scheme, Table 2 shows the comparison of total BER and PSNR of EEP and UEP by giving the number of error bits when the signal-to-noise ratio (SNR = 2.0 dB) are the same.

<table>
<thead>
<tr>
<th>Frame sequence</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Total BER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex1’s number of error bits:</td>
<td>6</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>10</td>
<td>2</td>
<td>6</td>
<td>0</td>
<td>0.0020</td>
</tr>
<tr>
<td>Ex2’s number of error bits:</td>
<td>0</td>
<td>22</td>
<td>8</td>
<td>18</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>11</td>
<td>8</td>
<td>2</td>
<td>0.0034</td>
</tr>
<tr>
<td>Ex3’s number of error bits:</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>2</td>
<td></td>
<td></td>
<td>0.0019</td>
</tr>
</tbody>
</table>

| Frame sequence | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | PSNR |
|----------------|----|----|----|----|----|----|----|----|----|----|      |
| Ex1’s number of error bits: | 0 | 6 | 0 | 5 | 0 | 17 | 4 | 8 | 0 | 0 | 9.3427 |
| Ex2’s number of error bits: | 0 | 0 | 2 | 0 | 15 | 26 | 0 | 10 | 6 | 0 | 15.8950 |
| Ex3’s number of error bits: | 0 | 6 | 0 | 4 | 2 | 8 | 6 | 24 | 0 | 0 | 21.4604 |

From the above data we can see that Ex1 and Ex2 are most representative groups in the EEP experiments. In Ex1 first frame transforms 6 bits’ error bits, while in Ex2 there is no error in the first frame. Although the total BER of Ex1 is lower than Ex2, but its PSNR value is lower than Ex2, and from image we can see that the result of Ex2 shows the broad contours of image while the result image of Ex1 is unrecognizable. It shows that important information is sensitive to error, although the BER of Ex3 is similar to Ex1, because the location of error bits are different, so the PSNR value of reconstructed image of Ex3 is bigger. Experimenting in condition of UEP for numbers of times, the results show that the first five frames’ accuracy is ensure in this way, so the problem of not rebuilding the image would not happen in condition of EEP. From Fig. 8(a) (EEP SNR=2.0dB, PSNR=9.3427), we can see that SPECK using the block-based coding structure, when error bit happens in transmission, only the block that has error bits is influenced. SPECK coding has strong error tolerance and overcomes the shortcomings of EZW that error bit will influence the whole structure of tree and having great damage to image. When SNR is 1.0 dB, the experiment is operated in condition of EEP. The image is unable to rebuild when the PSNR value is only 7.94 in EEP condition. When the experiment is in condition of UEP, the image can be rebuilt. We also learnt the average PSNR value can be 20.65 in this condition (as shown in Fig. 8(d)). There're another two examples shown in Fig. 8(b) (EEP SNR=2.0dB PSNR=15.8950) and Fig. 8(c) (UEP SNR=2.0dB, PSNR=21.4606).
In this paper, the experiments are in conditions of UEP and EEP when SNR is from 0.5 dB to 3.0 dB. Image after processing is difficult to identify because some results of the experiments are close to each other. In this paper, the PSNR value is shown instead of image after processing, in order to get data more objectively, we repeat every kind of experiment 30 times and averaging the results. The results are shown in Fig. 9. As shown in the Fig. 9, when SNR is high, the performance of EEP and UEP is close to each other, and if the SNR decline, the performance of EEP declines sharply. At the same time, the performance of UEP is being stabilized, the PSNR value is at least 20 or more. Foregoing, this paper presents that Joint Source-Channel Coding scheme is conducive to the error control for image in high-noise channel, Giving full consideration to the information of the source coding when channel coding, it makes error control more targeted. As seen from the simulation results, whether it’s the subjective feeling of image quality evaluation or using objective mathematical formula PSNR, the quality of reconstructed image in condition of joint coding type UEP after being transmitted in high-noise channel is obviously better than image that is in condition of separation coding type EEP.

Fig. 9. The comparison of performance of EEP and UEP.

5. Conclusions

Joint Source-Channel Coding can achieve a better balance between characteristic of real-time and high-quality reconstructed image in the image transmission for the needs of practical application. According to the degree of importance of data stream after source encoding, it does channel coding of different bit rates. At the decoding, on the basis of different bit rates, it chooses different iterations. This method will speed up the decoding speed, lower latency, and also get a better reconstructed image quality.

Acknowledgments

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