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Digital Watermarking Algorithm Based on Space-Time Coding

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Abstract

Theories of spread spectrum communications, channel coding, capacity analysis techniques have been widely applied in digital watermarking research. In recent years, communication theory has made an important technological breakthrough. The next generation mobile communication systems (4G) is far exceeding the capacity needs of the traditional Shannon channel capacity limit, and this need promotes the rapid development of multiple-input multiple-output (MIMO) technology. The combination of space-time coding and MIMO technology will breakthrough the capacity limit of single-input single-output (SISO) channel. In this paper, the digital image watermarking system is extended from SISO to MIMO systems based on space-time coding and MIMO communication theory. The new watermarking algorithm is designed in the new framework of space-time coding and MIMO-based communication theory. The watermark capacity and the detection error rate also are further studied under the conditions of different space-time coding. These studies will provide a new idea for the design of new digital watermarking algorithm.

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Keywords: digital image processing; digital watermarking; MIMO; space-time coding

1. Introduction

With the rapid development of digital technology, digital media (images, video, audio, and 3D computer graphics, etc.) is widely used. Especially with the development of computer network and communication technology, data exchange and transmission become a relatively simple process. With computers, digital scanners, printers and other electronic equipment, people can easily transmit digital information around the world. Digitization of multimedia information provides a great convenience, but the attendant problem of information security has become more obvious, the security of digital media content is an urgent need to address the problem.

Digital watermarking is the process of embedding information into a digital signal in a way that is difficult to remove. The signal may be audio, pictures or video, for example. If the signal is copied, then the information is also carried in the copy. A signal may carry several different watermarks at the same time. In visible watermarking, the information is visible in the picture or video. Typically, the information is text or a logo which identifies the owner.

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of the media. The image on the right has a visible watermark. When a television broadcaster adds its logo to the
corner of transmitted video, this is also a visible watermark. In invisible watermarking, information is added as
digital data to audio, picture or video, but it cannot be perceived as such (although it may be possible to detect that
some amount of information is hidden). The watermark may be intended for widespread use and is thus made easy
to retrieve or it may be a form of Steganography, where a party communicates a secret message embedded in the
digital signal. In either case, as in visible watermarking, the objective is to attach ownership or other descriptive
information to the signal in a way that is difficult to remove. It is also possible to use hidden embedded information
as a means of covert communication between individuals.

In the digital watermarking algorithm based on communication theory, we can view the process of watermark
embedding and extraction as a communication process. The host data (such as images) can be viewed as a
communication channel; the watermark can be viewed as the signal which needs to transmit in the channel. Then the
watermark embedding and extraction can be viewed as the process that a signal (watermark) is transmitted in an
channel (the original data). Currently, the studies of digital watermarking widely adopt the theories of spread
spectrum communication and channel coding.

Digital watermarking based on communication theory is a very clever way to creatively introduce the
communication theory, information theory into the study of the watermark. In addition to using spread spectrum
technology and channel coding designing high performance digital watermarking algorithm, the watermarking
capacity analysis has become possible. Watermark capacity is simply the number of host data to hide the watermark.
If we do not using the information theory method, analysis of watermark capacity is very difficult. In digital
watermarking based on communication theory, we can use Shannon formula of information theory to analyze
watermarking capacity problem. The current digital watermarking research is based on a single antenna system, the
single-input single-output (Single Input Single Output, SISO) system.

Almost all current digital watermarking capacity research is based on communication theory. In the early
capacity research, each pixel of images is viewed as an independent AWGN (Additive White Gaussian Noise)
channel. When we assume the noise is Gaussian white noise, we can calculate capacity of each pixel of the
watermark, and then use the parallel Gaussian channel model to calculate the entire watermark capacity of
image. Lin studied an analysis of capacity in JPEG compressed domain with zero error rates, also use a similar idea
[1]. Moulin and Mihcak studied the property of a single Gaussian channel, and think that the capacity of parallel
Gaussian channels is the weighted sum of each sub-channel capacity [2]. Barni analyzed the image watermarking
capacity in DCT and DFT transform [3]. Barni think that the DCT coefficient distribution can be represent by
generalized Gaussian distribution, and DFT coefficients subject to Weibull distribution. Barni study the image
watermark capacity using the maximum mutual information method.

2. Multiple Input Multiple Output and Space-Time Coding

In recent years, communications technology has developed rapidly. Next-generation mobile communication
system (4G) provides higher data rates than the existing 2G, 3G systems. The capacity demand far exceeds the
traditional Shannon channel capacity limit, and using the traditional means of communication can not provides such
a high channel capacity. So in order to breakthrough the classical Shannon channel capacity limit, the new theory
must be supported. This demand drives multi-input multi-output (Multiple Input Multiple Output, MIMO)
technology's rapid development.

According to Shannon information theory, a single antenna system can not exceed the capacity limit due to the
bandwidth. So to address capacity problem must finding another way because of the restrictions on the receiver
signal to noise ratio, spectrum resources, and operating costs. Multi-antenna technology is the only effective method.
In the MIMO system, multiple antennas (or antenna array) are used both in the transmitter and the receiver. Through
the appropriate design of signals, multi-antenna technology can improve system capacity without significantly
increase the cost of wireless communication.

MIMO system can create multiple parallel spatial channels. Through these parallel spatial channels we can
transmit information independently, and the capacity can also increase. We say the system get the Spatial
Multiplexing Gain. The researches show that when power and bandwidth is fixed, the maximum capacity or
capacity limit of MIMO system increase linearly with the minimum number of antennas.
Because of the characteristics of wireless channel fading, the signal of single antenna system may exist deep fading. In the multi-antenna system, if the antenna spacing is far enough, we can ensure the signal fading independent in different antenna. Therefore, the SNR of the combined received signal will become smooth fluctuations, thereby improving the quality of the received signal. We say the system get the Space Diversity Gain. Using multi-antenna technology, we can also get the Power Gain, Array Gain and Co-channel Interference Reduction Gain.

In order to transmit signals on multiple antennas, we need special code the signal, this technique called space-time coding. Space-time coding is the combination of multi-channel coding design and multiple antennas transmission. MIMO system can achieve very high capacity through multiple antennas transmitting multiple data streams, and the optimal processing on multi-antenna receiver. The best processing is realized through the space-time coding and decoding. Through space-time encoded, data is converted into multiple strings and data flow. After the modulation, different signals are sent to the wireless space within different time slots through multiple antennas. Space-time coding combines the transmission of space and time, essentially is a two-dimensional space and time method.

Using of space-time coding and MIMO techniques, we can provide the best spatial multiplexing gain, space diversity gain, and coding gain. Spatial multiplexing can significantly increase the channel capacity, and space diversity can improve the reliability of the channel and reduce the bit error rate. Combining space-time coding and MIMO technology, we can breakthrough the capacity limit of single-input single-output (SISO) channel. MIMO and space-time coding has become the standards of fourth generation (4G) mobile communications.

AT & T Bell Laboratories derive MIMO channel capacity firstly [4]. The results show that the $N \times M$ channel matrix describes system of wireless channel with $M$ transmitting antenna and $N$ receive antenna, if the ideal independence fading exist between the elements of $N \times M$ channel matrix, the system capacity will increase with the number of antennas increases linearly in the launch and receiving sides which with the smallest number of antenna. This will multiply the system capacity.

In recent years, space-time coding techniques have also been widely studied. Many kinds of space-time codes are studied, including BLAST (LSTC) [5], space-time Trellis Code (STTC) and space-time block code (STBC) [6]. The current 3G WCDMA and CDMA2000 has adopted the STBC diversity transmitting scheme. Other relatively new space-time codes also include unitary space time code (USTC), and differential space-time code (DSTBC), etc. [7]. Hassibi proposed maximization linear dispersion codes (LDC) based on mutual information [8]. Heath proposed a design criterion of linear discrete code based on diversity gain [9]. In MIMO systems, diversity gain and multiplexing gain can not be the biggest simultaneously; Zheng and Tse solve the tradeoff problem of diversity gain and multiplexing gain [10]. Another current research focus is the MIMO-OFDM system which combined orthogonal frequency division multiplexing (OFDM) with MIMO technology [11]. In this system, we can use spectrum resources efficiently, not only get high transmission efficiency, but also get strong reliability through diversity achieved.

3. Digital Watermarking Algorithm Based on MIMO Communication

3.1 To enhance the reliability of watermarking detection

MIMO technology is essentially to provide spatial multiplexing gain and spatial diversity gain, so currently research on MIMO channels is mainly about these two aspects. Spatial multiplexing can significantly increase the channel capacity, and space diversity can improve the reliability of the channel and reduce the bit error rate. Space-time block code is the space-time codes which can achieve maximum diversity gain, so we use space-time block codes to design new digital watermarking algorithm.

Space-time block coding distribute the transmitting signal using the principle of orthogonal design, actually it is a combination of spatial domain and time domain orthogonal block encoding. This paper uses the Alamouti space-time block coding scheme. The key feature of this scheme is to ensure the orthogonality between the two sequences of two transmitting antennas, and to obtain maximum diversity gain. Figure 1 shows watermarking algorithm based on Alamouti space-time block coding.

The watermarking algorithm based on Alamouti space-time blocks coding use two-input single-output MIMO channel. Firstly, the watermark information been convolutional coded to further improve the watermark detection
reliability. Then the convolution encoded watermark is divided into two symbol group \([s_1, s_2]\), while the original image is embed by the two signals. In the first symbol period, signal \(s_1\) and \(s_2\) are embedded separately. In the second symbol period, signal \(-s_2^*, s_1^*\) are embedded respectively, in which \(s^*\) representatives the complex conjugate of the signal \(s\). The key idea of Alamouti space-time block coding is to make the signal vector on the two antennas to send orthogonal each other, that is, the two signal vectors \(S_1=[s_1, -s_2^*]\) and \(S_2=[s_2, s_1^*]\) is mutual orthogonal. In the watermarking information extraction, after channel estimation and signal merger, the linear maximum likelihood (ML) decoder is used to detect the hidden information, and recover the watermark through de convolution.

3.2 To increase the capacity of digital watermarking

In order to improve the channel capacity, MIMO communication can send different data streams in different antenna, to achieve the maximum multiplexing gain. Such as BLAST (Vertical Bell labs Layered Space Time architecture) structure, transmits independent information flow within multiple parallel spaces, and increases the data transfer rate. BLAST structure is divided into V-BLAST, D-BLAST and so on. In this paper, the proposed watermarking algorithm using D-BLAST structure which is based on layered space-time coding, 2×2 MIMO channel. It is shown in Figure 2.
Firstly, the watermark data stream is divided into two sub-parallel data flows, each data flow carries out a separate channel coding. Then space-time block-based interleaving is performed in these sub-streams, which makes the watermark signal generate the diagonal stratification in space and time. The two-way data throughput the space-time block-based interleaving is embedded into the original image respectively. Watermarking information is extracted by zero forcing (ZF) detection and space-time decoding, and de-interleaving and channel decoding, then get the final recovered watermark.

4. Capacity of Watermarking Based on MIMO Communication

In MIMO system, assuming that the system transmitter has $M$ antennas, the receiver has $N$ antennas, the total transmit power is $P$, then the power of each transmitting antenna is $P/M$. The total power of each receiving antenna is equal to the total transmit power. Assuming that channel is interfered by additive white Gaussian noise (AWGN), and the noise power is $\sigma^2$ in each receive antennas, then the signal to noise ratio (SNR) in each receive antennas is: $\xi = P/\sigma^2$. $M \times N$ complex matrix $H$ channel denotes the transfer function of transfer matrix, and $H^H$ is the Hermitian (complex conjugate) transformation of matrix $H$.

For the deterministic single-input single output (SISO) channel, since $M = N = 1$, the channel matrix $H = 1$, SNR is $\xi$, according to Shannon formula, the normalized channel capacity can be expressed as:

$$ C = \log_2 (1 + \xi) \quad (1) $$

For the multiple-input multiple-output (MIMO) channel, the channel capacity can be expressed as:

$$ C = \log_2 \left| \det \left( I_{\min} + \frac{\xi}{M} Q \right) \right| \quad (2) $$

where $\min$ is the smaller of $M$ and $N$, $I_{\min}$ is unit matrix of $\min \times \min$, $\det$ express matrix determinant, then matrix $Q$ is defined as follows:

$$ Q = \begin{cases} H^H H, & N < M \\ H H^H, & N > M \end{cases} \quad (3) $$

In the communication theory, the channel capacity of a $M \times N$ system is at least $\min (M, N)$ times to the channel capacity of a SISO system.

Given above is the basic form of MIMO channel capacity under ideal conditions. For space-time coding and MIMO communication based digital image watermarking, because the image space is limited, the created image MIMO communication channel is not ideal. Generally we can not ensure that all the sub-channels are completely unrelated, which will result the space can not be fully utilized and will certainly reduce the MIMO channel capacity. Therefore, the channel matrix $Q$ need be amended in watermark capacity analysis of this paper. A correlation matrix is introduced in both side of watermarking embedding and extracting, and then according to the different space-time coding watermarking algorithm, watermarking capacity formula is derived. Monte Carlo simulation method is used test the performance of proposed watermarking algorithm. Finally, we can analyzes and compare the different watermark capacity with different circumstances between space-time coding and MIMO channel model.

5. Conclusions

In this paper, the digital image watermarking system is extended from SISO to MIMO systems based on space-time coding and MIMO communication theory. The new watermarking algorithm is designed in the new framework of space-time coding and MIMO-based communication theory. The watermark capacity and the detection error rate
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