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RESEARCH ARTICLE

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Study and simulation of video communications under wireless environment based on blind source separation

Abstract A new scheme is proposed to separate several compressed video signals transferred in multiple wireless channels using the blind source separation method. The scheme selects IEEE 802.11b and XVID compression as the wireless communications channel and MPEG-4 video compression, respectively. A simulation model is then made for the video communications under a wireless environment. The model can separate several video signals using blind source separation. Simulations show that the normalized whiten plus cyclic whiten based on cyclostationary (NWCW-CS) algorithm based upon the cyclostationary characteristics of signals has the best separation performance and fast convergence. Besides, the algorithm can solve the mixing of video signals. The image of the transferred video signals decompressed by XVID is nearly consistent with the source ones. The new method meets the requirement of real-time video communications.

Keywords blind source separation, cyclostationary, video, MPEG-4, wireless local area network

1 Introduction

The technologies of radio communications and video signal processing are developing rapidly. Limited by bandwidth, the video data should be compressed before transmitting. MPEG-4 has become the major format of video compression for its characteristics on high compressibility and good quality. In this paper, multiple video data are compressed by the standard of MPEG-4 and transmitted through wireless local area network (WLAN). It can be widely applied for family and business use.

The multi-path effect, shielding and noise interference in the wireless channel may cause stochastic errors and burst errors to video flow. However, the standard of MPEG-4 and WLAN has corresponding error tolerance mechanism. Besides, multiple video signals will be mixed because of the coupling between channels. Therefore, how to separate the mixed signals is the primary concern of this paper. The blind source separation method, which is valuable for image and speech areas, has recently become an important topic in the signal processing field.

This paper first introduces the blind source separation method, and then supposes that modulated video signal is characterized by cyclostationary in the wireless channel. Secondly, the WLAN video communications system model is defined, adopting IEEE 802.11b as the wireless video communications environment and XVID as the MPEG-4 video compression scheme. According to the model, the separation effect is simulated for multiple video data by the blind source separation algorithm. Finally, conclusions are presented.

2 Blind source separation and cyclostationary

Blind source separation can be described as follows. As shown in Fig. 1, there are n unknown signals from different signal sources and m receiving sensors, and the receiving end reconstructs the unknown source signals only by receiving signals. $\boldsymbol{s}(t)$ is an n dimensional source signal, $\boldsymbol{A}$ is an $m \times n$ dimensional mixing matrix. $\boldsymbol{x}(t) = \boldsymbol{A}\boldsymbol{s}(t)$ is an m dimensional receiving signal. The blind source separation recovers the source signal $\boldsymbol{y}(t) = \boldsymbol{B}(t)\boldsymbol{x}(t)$, where $\boldsymbol{B}(t)$ is the separation matrix, $\boldsymbol{y}(t)$ is the n dimensional recovery signal.

Most communications signals are cyclostationary, thus we use the cyclostationary characteristic to analyze the blind source separation [1,2]. The statistics of cyclostationary signal is characterized by periodical variation,

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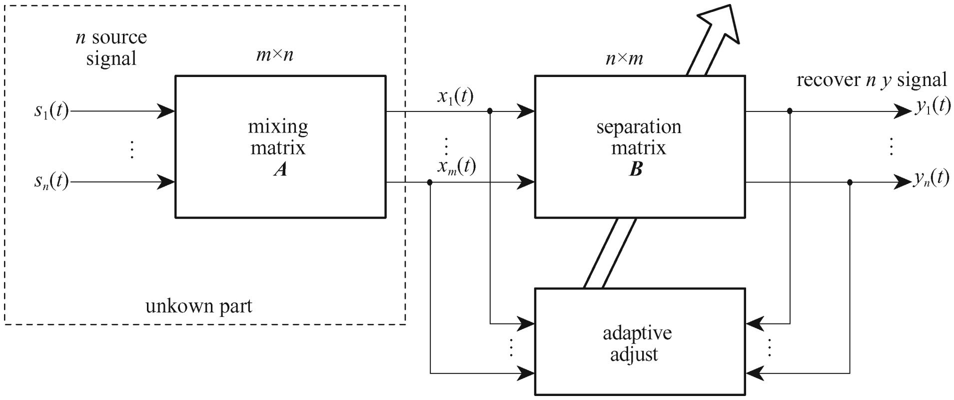

Fig. 1 Basic figure on blind source separation

and its cyclic frequency depends on carrier frequency and bit rates of signal [3]. Many familiar modulated signals have cyclostationary characteristics. Because the video signal analyzed in this paper is modulated signal, the video signal can be assumed as a cyclostationary signal. The signals can be distributed on different cyclic frequencies, which hence can be utilized to obtain good separation effect.

3 Multiplexing wireless video transmitting and application scheme

Featuring low cost, low power consumption and flexible network, the technology of wireless video communications is applicable in various situations [4,5]. IEEE 802.11b works at 2.4 GHz frequency, which is applicable for its compatibility under IEEE 802.11. Therefore, this paper chooses IEEE 802.11b as the WLAN video communications environment.

The WLAN network has 3 forming modes: point-to-point mode, multi–point-to-point mode and full distributing mode [6]. Among these modes, the multi–point-to-point mode can effectively utilize signal transmitting power, which makes it easy to connect with the Ethernet. thus, it has been applied frequently. As shown in Fig. 2, the multi–point-to-point network structure is the multiple video communications system under discussion. After the video collection terminal compressed the video data, the data are transmitted to an access point (AP) through wireless channel. The system uses the MEPG-4 standard to compress video for transmitting. Besides, it also utilizes a modulation technique. The basic structure of the wireless video communications system is shown in Fig. 3, where the multiple video signals are modulated. Thus, it can be assumed as cyclostationary.

MPEG-4 compresses data by frame rebuilding, using the fewest data to gain the best image effect, which has been the main trend of recent video encoding and decoding. The practical encoder based on MPEG-4 includes ISO Encoder, DIVX and XVID, etc. Because the source code of XVID is entirely open with fast compression, the XVID encoder is utilized in this paper. The source code of this encoder can be obtained from the official website and the present edition is xvid-core-1.1.0.

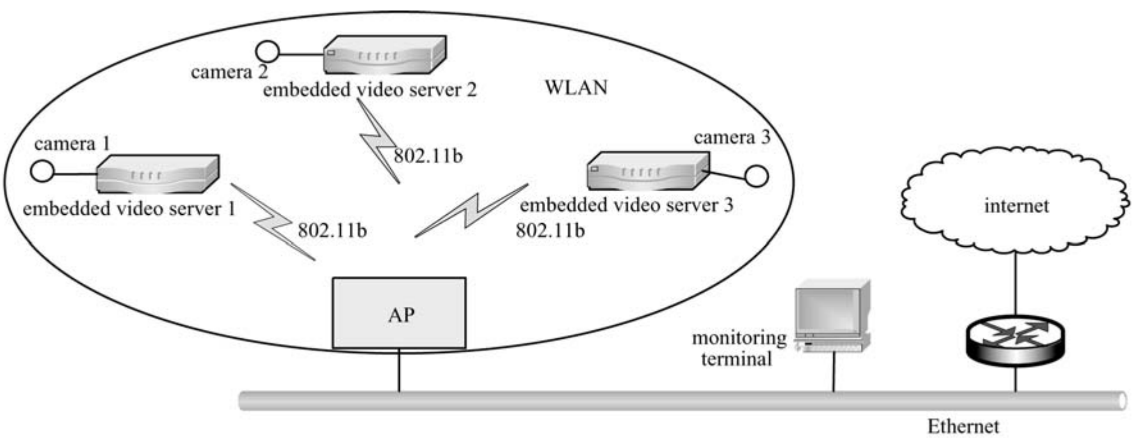

Fig. 2 Structure of multiple wireless video transmitting network

4 WLAN video communications system and simulation model

4.1 Simulation model

IEEE 802.11b is used to simulate the channel. The protocol works at 2.4 GHz frequency, with a transmission rate that can reach 11 Mb/s. The model solves multiple signal separation problems of the blind source separation method.

The specific modulation model is shown in Fig. 4. The model is composed of signal sending terminal, channel and receiving terminal and receiving control part. The sending terminal compresses video flow and modulations signals. We suppose the channel to be a mixed matrix according to the blind source separation theory [4]. At the receiving terminal, it first obtains the separation matrix by the adaptive algorithm, then uses the separation matrix to separate mixed useful signals. Finally, by demodulation and XVID decompression, the terminal obtains the recovering video data. In the receiving control part, we consider the estimation of carrier frequency order. The terminal can correctly demodulate original signals through estimation. The estimation can also offer correct cyclic frequency for the adaptive algorithms.

The modulation model designs the process of algorithm training and the switch control of video transmitting process. First, for algorithm training, the blind source separation algorithm combines the satisfactory separation matrix by training sequence. Second, the model switches to video transmitting process, using the fix value separation matrix to separate video data. Through the adaptive training convergence and real time video separation, the system can satisfy the real-time requirement of video transmitting.

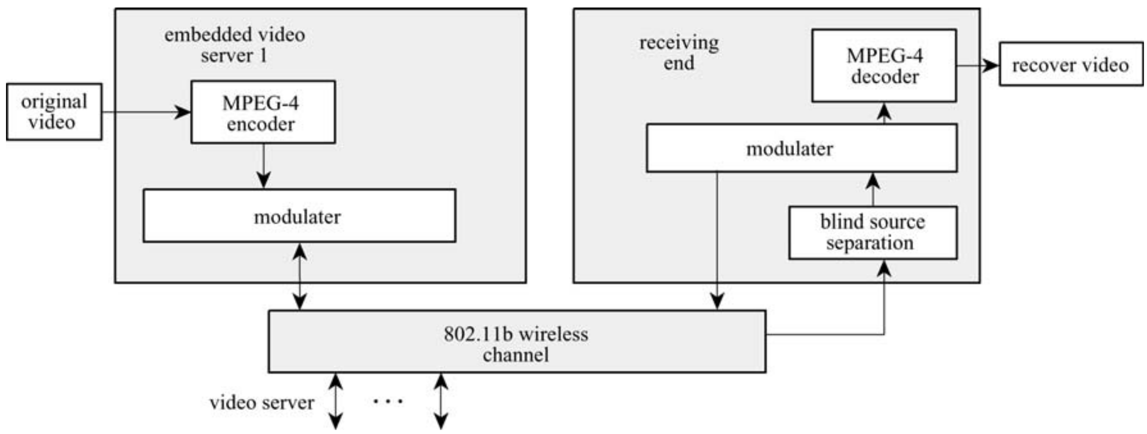

Fig. 3 Basic structure of wireless video communications system

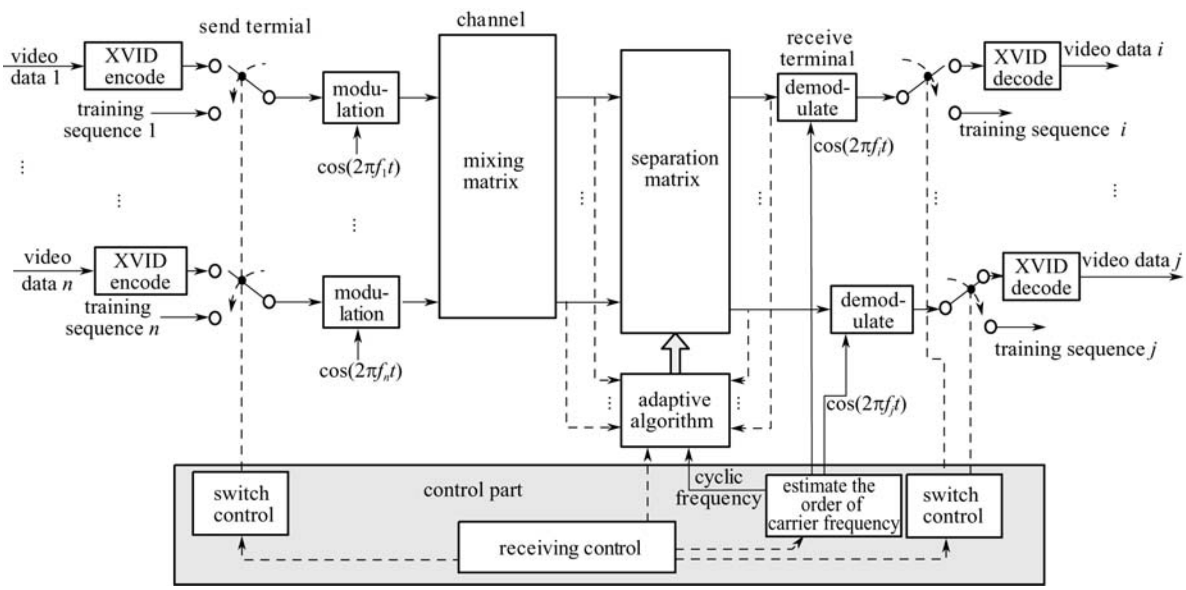

Fig. 4 WLAN video communication simulation model

4.2 Algorithm of blind source separation

The time in Fig. 1 should be discretized in simulation. $\boldsymbol{s}(k)$ is the source signal and $\boldsymbol{x}(k) = \boldsymbol{A}\boldsymbol{s}(k)$ is the receiving signal. The blind source separation result is $\boldsymbol{y}(k) = \boldsymbol{B}(k)\boldsymbol{x}(k)$, where $\boldsymbol{B}(k)$ is the separation matrix, $\boldsymbol{y}(k)$ is the recovering signal. The source signal $s_i(\underline{k})$ is the modulated signal. The assumption conditions are as follows:

1) $\boldsymbol{A}$ is a full order matrix and $n = m$;
2) $s_i(\underline{k})$ is zero mean;
3) $s_i(\underline{k})$ is statistically independent;
4) $s_i(\underline{k})$ has unit variance;
5) $s_i(\underline{k})$ is a second-order cyclic process.

Four blind source separation algorithms are compared, i.e., the natural gradient algorithm (NGA), the EASI algorithm [7], the NGA based on cyclic statistics [8,9] and the WCW-CS algorithm. Their adapting equations of separation matrix are as follows:

$$\boldsymbol{B}(k+1) = \boldsymbol{B}(k) - \mu\left[\boldsymbol{g}(\boldsymbol{y}(k))\boldsymbol{y}^{\mathrm{T}}(k) - I\right]\boldsymbol{B}(k), \tag{1}$$

$$\begin{aligned}\boldsymbol{B}(k+1) = \boldsymbol{B}(k) - \mu\big[&\boldsymbol{y}(k)\boldsymbol{y}^{\mathrm{T}}(k) - \boldsymbol{I} + \boldsymbol{g}(\boldsymbol{y}(k))\boldsymbol{y}^{\mathrm{T}}(k) \\ &- \boldsymbol{y}(k)\boldsymbol{g}^{\mathrm{T}}(\boldsymbol{y}(k))\big]\boldsymbol{B}(k),\end{aligned} \tag{2}$$

$$\begin{aligned}&\boldsymbol{B}(k+1) \\ &= \boldsymbol{B}(k) - \mu[\boldsymbol{g}(\boldsymbol{y}(k))\boldsymbol{y}^{\mathrm{T}}(k) - \boldsymbol{I} + \sum_{i=1}^{n} \boldsymbol{R}_y^{\beta_i}(k,0) - I]\boldsymbol{B}(k),\end{aligned} \tag{3}$$

$$\begin{aligned}\boldsymbol{B}\ (k+1) = \boldsymbol{B}(k) - \mu[&\boldsymbol{R}_y(k,0) - \boldsymbol{I} + \sum_{i=1}^{n} \boldsymbol{R}_y^{\beta_i}(k,0) - I \\ &+ \boldsymbol{g}(\boldsymbol{y}(k))\boldsymbol{y}^{\mathrm{T}}(k) - \boldsymbol{y}(k)\boldsymbol{g}^{\mathrm{T}}(\boldsymbol{y}(k))]\ \boldsymbol{B}(k),\end{aligned} \tag{4}$$

where $\boldsymbol{R}_y(\tau)$ is the auto correlation matrix of receiving signals, $\boldsymbol{R}_y^{\beta_i}(\tau)$ is the cyclic auto correlation matrix of receiving signals, β_i is the cyclic frequency of signals, k is the discrete time under simulation, μ is the fixed iteration step size, $\boldsymbol{g}(\boldsymbol{y}(k))$ is the non-linear odd function of $\boldsymbol{y}(k)$, and the non-linear function is $g_i(y_i) = y_i^3$.

To improve the stability of the algorithms, we can normalize the EASI and WCW-CS algorithms [7], and obtain the NEASI and NWCW-CS algorithms as follows:

$$\begin{aligned}\boldsymbol{B}(k+1) = \boldsymbol{B}(k) - \mu\Bigg[&\frac{\boldsymbol{y}(k)\boldsymbol{y}^{\mathrm{T}}(k) - \boldsymbol{I}}{1 + \mu\cdot\boldsymbol{y}^{\boldsymbol{T}}(k)\boldsymbol{y}(k)} \\ &+ \frac{\boldsymbol{g}(\boldsymbol{y}(k))\boldsymbol{y}^{\mathrm{T}}(k) - \boldsymbol{y}(k)\boldsymbol{g}^{\mathrm{T}}(\boldsymbol{y}(k))}{1 + \mu|\boldsymbol{y}^{\boldsymbol{T}}(k)\boldsymbol{g}(\boldsymbol{y}(k))|}\Bigg]\boldsymbol{B}(k),\end{aligned} \tag{5}$$

$$\begin{aligned}\boldsymbol{B}(k+1) = \boldsymbol{B}(k) - \mu\Bigg[&\frac{\boldsymbol{R}_y(k,0) - \boldsymbol{I}}{1 + \mu\mathrm{tr}(\boldsymbol{R}_y(k,0))} + \frac{\sum_{i=1}^{n} \boldsymbol{R}_y^{\beta_i}(k,0) - I}{1 + \mu\mathrm{tr}\left(\sum_{i=1}^{n} \boldsymbol{R}_y^{\beta_i}(k,0)\right)} \\ &+ \frac{\boldsymbol{g}(\boldsymbol{y}(k))\boldsymbol{y}^{\mathrm{H}}(k) - \boldsymbol{y}(k)\boldsymbol{g}^{\mathrm{H}}(\boldsymbol{y}(k))}{1 + \mu|\boldsymbol{y}^{\mathrm{H}}(k)\boldsymbol{g}(\boldsymbol{y}(k))|}\Bigg]\boldsymbol{B}(k).\end{aligned} \tag{6}$$

The separation effect of the blind source separation can be measured by the performance index (PI). The PI is expressed by combined matrix $\boldsymbol{C}(k) = \boldsymbol{B}(k)\boldsymbol{A}$, where $\boldsymbol{C}(k) = [c_{ij}]$. The smaller PI is, the better the separation effect will be. PI is defined as

$$\begin{aligned}\mathrm{PI} = &\frac{1}{n}\sum_{i=1}^{n}\left(\sum_{j=1}^{m}\frac{|c_{ij}|^2}{\max_k|c_{ik}|^2} - 1\right) \\ &+ \frac{1}{m}\sum_{j=1}^{m}\left(\sum_{i=1}^{n}\frac{|c_{ij}|^2}{\max_k|c_{kj}|^2} - 1\right).\end{aligned}$$

5 Simulation results and analysis

5.1 Comparison of blind source separation algorithms

The simulation aims to find an optimal blind source separation algorithm through comparison. The input training sequence is 1000 bits and the separation signal number is supposed to be 3.

First, using Eqs. (1)–(4) to compare the four blind source separation algorithms. The simulation parameters are as follows: The signal is DBPSK modulation signal, carrier-modulated by $\cos(2\pi f_1 t)$, $\cos(2\pi f_2 t)$ and $\cos(2\pi f_3 t)$ respectively, where $f_1 = 2.422$ GHz, $f_2 = 2.442$ GHz, $f_3 = 2.422$ GHz, and the cyclic frequencies are $\beta_1 = 4.844$ GHz, $\beta_2 = 4.884$ GHz, $\beta_3 = 4.844$ GHz. The simulation discrete iteration time is $N = 20000$, and the iteration step size is $\mu = 0.00047$.

The simulation results are shown in Fig. 5(a). The convergence rates of the four blind source separation algorithms are NGA, NGA-CS, EASI and WCW-CS, in an order from slow to fast. When the PI reaches 0.01, the iteration times of the four algorithms are 10135, 8569, 8283 and 5040 respectively. It can be concluded that the WCW-CS algorithm has the best convergence performance. Besides, the algorithms based on cyclostationary features are better than the former algorithms, but require more calculation.

The four algorithms are then compared according to Eqs. (2), (4)–(6) and the simulation results are shown in Fig. 5(b). The convergence rates in an ascending convergence speed are EASI, NEASI, WCW-CS and NWCW-CS. When the PI reaches 0.01, the iteration times of the four algorithms are 8283, 4687, 5040 and 3818 respectively. It can be concluded that normalized algorithms

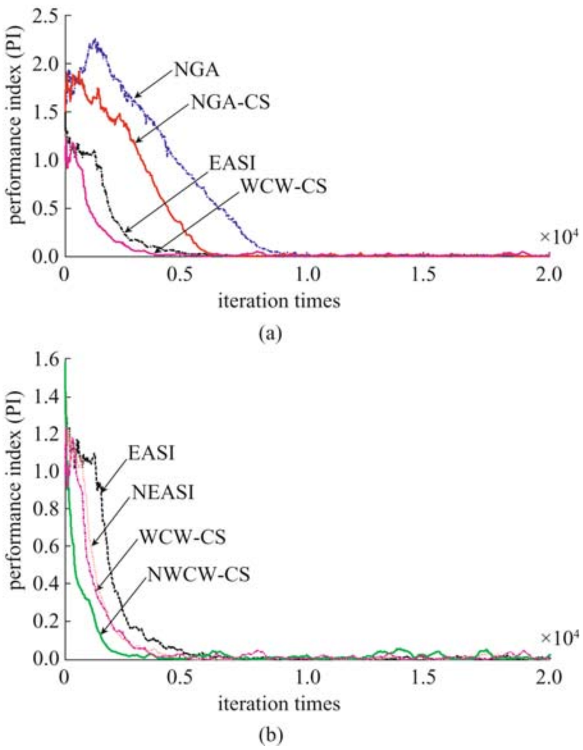

Fig. 5 Comparison of blind source separation algorithms. (a) Comparison of four blind source separation algorithms in convergence; (b) comparison of two blind source separations with their normalized algorithms

have better performance than original algorithms and has faster convergence. NWCW-CS algorithm has the best performance and fastest convergence. Therefore, we choose this algorithm for the multiple video signal separation simulation.

5.2 Simulation of video signal separation

The simulation uses NWCW-CS algorithm to separate video compression signals. The 3 video data flows are news, carphone and mother respectively, excerpted from http://www.cipr.rpi.edu. Then the system compresses these video flows according to the XVID standard. The parameters are as shown in Table 1.

Table 1 Comparison on parameters of XVID video (3 videos)

	news	carphone	mother
average compression time/ms	5.33	5.33	3.88
average frame size/b	4256	4935	2056
average decompression time/ms	10.67	10.33	5.88

The simulation parameters are identical with those in Sect. 5.1. According to Fig. 4, switch the function to video transmitting process and the separation matrix $\boldsymbol{B}$ is a fixed value.

Figure 6 is the waveform comparison of 3 video signals separation. Figure 7 is the separation performance of the 3 video signals according to the second frame. As shown in Fig. 6, s_i is the waveform of source video signals, x_i is the waveform of mixed video signals, and y_i is the waveform of separated video signals. From Fig. 6, although the 3 waveforms of source signals are mixed by the mixing matrix, the separating matrix can also recover the original waveform. However, the location of signal 2 and signal 3 is crossed. As shown in Fig. 7, the 3 video signals are consistent between the original and the recovered signals. Without the blind source separation process, as shown in Fig. 7(b), the picture effect would be unsatisfactory.

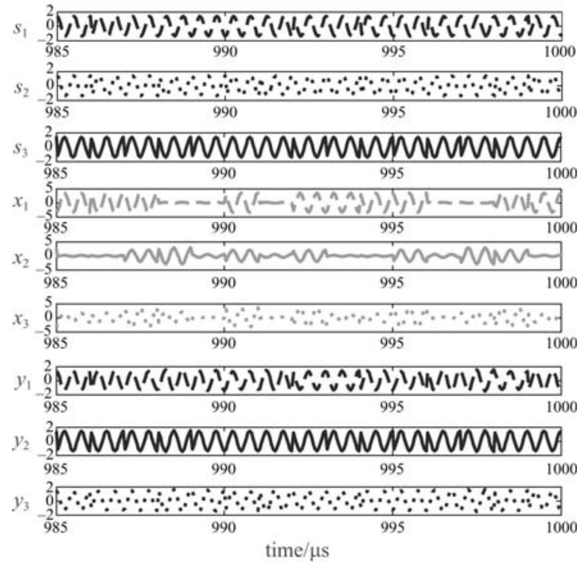

Fig. 6 Waveform comparison of 3 video signals separation

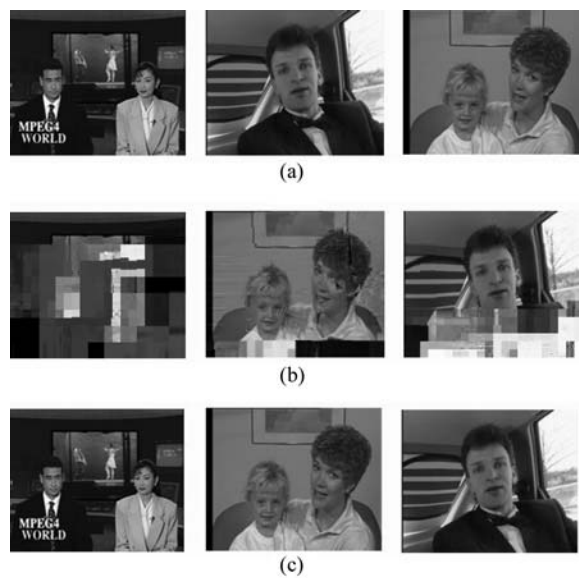

Fig. 7 Separation performance of 3 video signals. (a) Source video signals; (b) mixed video signals; (c) separated video signals

The input video flows are then changed for simulation. The two input video signal flows are from cactus and picture, where the cactus is the XVID testing sequence and the picture video flow is gathered by cameras. The parameters are shown in Table 2.

Table 2 Comparison on parameters of XVID video (2 videos)

	cactus	picture
average compression time/ms	15.67	15.34
average frame size/b	8819	5178
average decompression time/ms	10.67	10.75

The simulation parameters are as follows: The signals are carrier-modulated by $\cos(2\pi f_1 t)$ and $\cos(2\pi f_2 t)$, where $f_1 = 2.422$ GHz, $f_2 = 2.442$ GHz, the cyclic frequencies are $\beta_1 = 4.844$ GHz, $\beta_2 = 4.884$ GHz, and the iteration step size is $\mu = 0.0004$. Figure 8 illustrates the separation performance of 2 video signals, according to the second frame. As shown in Fig. 8, the two video signals are basically consistent between the original and the recovered signals. Without the blind source separation process shown in Fig. 8(b), the picture effect would be unsatisfactory.

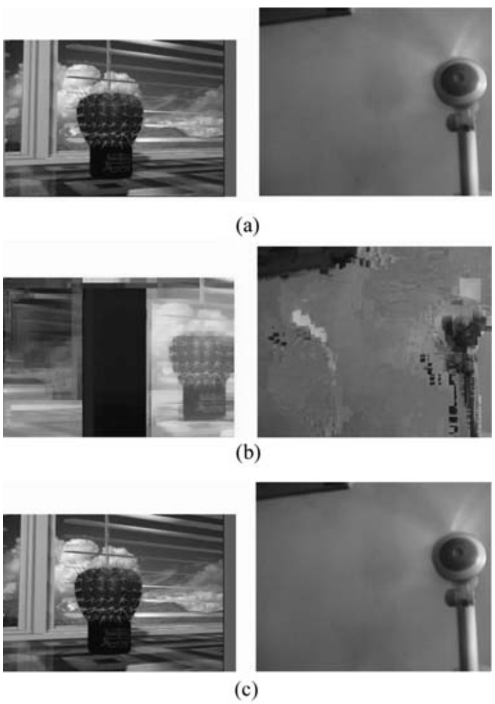

Fig. 8 Separation performance of 2 video signals. (a) Source video signals; (b) mixed video signals; (c) separated video signals

The experiment demonstrates that it is efficient to separate multiple video signals by blind source separation algorithms. The simulation model is shown in Fig. 4, and the blind source separation convergence is accomplished at the beginning of training the algorithm. When transmitting video signals, we employ the fixed separation matrix $\boldsymbol{B}$ to separate signals. Therefore, the blind source separation algorithm does not influence the video decompression, and thus guaranteeing the real-time quality of video transmission. Take the cactus video data that has the longest average frame for example. If the video is transmitted at the rate of 1 Mb/s according to IEEE 802.11b, the video flow can transmit 15 frames per second.

6 Conclusions

Wireless video communications systems have a large application potential. The blind source separation is a research hot spot in the signal processing field. This paper introduces blind source separation into the former for separating mixed multiple video signals. A blind source separation model is designed for multiple video compression signals under WLAN.

The simulation includes wireless communications, video signal gathering, MPEG-4 compression and decompression, and blind source separation. The source signal for blind source separation is from real MPEG-4 video compression signals, and wireless channel is defined as the IEEE 802.11b environment at 2.4 GHz frequency. Signal processing, wireless transmitting and video compression are combined in this paper. It has been verified that the simulation system can effectively enhance the performance of blind source separation and increase the convergence rate. Simulation results demonstrate that the NWCW-CS algorithm can effectively separate mixed video signals and satisfy real-time video transmission.

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