Data Hiding Using Binocular Fusion of Stereo Pairs

John Y. Chiang and N. Y. Bai

Abstract: In this paper, a data hiding algorithm, which employs the methodology of the binocular fusion of stereo image pairs, is introduced. The embedding data are hidden in the depth field of two matching stereo pairs. One of the stereo pairs is the original host image and the other is the counterfeit image derived from the embedding data, the focal length of cameras and the separation of the camera pairs. This mapping of the binocular fusion of stereo pairs to the problem of data hiding is motivated by the resemblance of left and right stereo images encountered in the stereographic projection setup. If one of the stereo pairs is a familiar image collected from a common database, the other stereo image will be similar to its matching counterpart possessing exactly the same pixel gray level with minor offset. This desirable property makes a human observer difficult to differentiate the counterfeit image from the original one. Therefore, a perfect candidate for hiding information. The performance of this novel approach is tested on different types of the host images and embedding data by examining the data hiding capacity and the PSNR between the host and counterfeit images. The result demonstrates the proposed algorithm obtain good performance in both measures.

Keywords: data hiding, binocular fusion, stereo pairs.

1. INTRODUCTION

Data hiding is a technology allowing data imperceptibly embedded into other digital media to protect contents from illegal copy, unauthorized distribution and tampering [1-3]. Hiding a message with steganographic methods reduces the chance of the information being detected [4]. Features desirable to data hiding techniques include invisible marking, inseparable marking and consistent data size. Invisible marking states that information embedded shall introduce little degradation to prevent human from noticing visually, while inseparable marking requires the data remained embedded even after transformation of the digital contents, e.g., compression [5-7]. Since the information is hidden directly into the host image, the data size before and after the embedding operation shall be consistent. In contrast to cryptography, where the detection, interception and modification of the messages are guarded by the security promises guaranteed by the cryptosystem, the goal of steganography is to hide messages inside other harmless host messages in a way that the very existence of the secret message is not detectable to invite any countermeasure. The coupling of data hiding and cryptography can provide a stronger measure to discourage illicit access for embedded data and the attempt to unscramble.

Data hiding methods encompass a wide spectrum of techniques in the fields of communication, image processing, cryptography, etc. One class of data hiding techniques concentrates on rearranging entries in binary documents by permuting close colors with similar frequency of occurrence or by permuting the palette entries rather than the image itself [8]. The entropy of the image will not change due to this permutation process. A large number of secure message hiding methods are based on modifying the least significant bits of the host image by encoding the message directly into the lower order bits of each pixel. This strategy can also be applied to transform-based compression image by modifying the lower order bits of the transform coefficients. Hiding information in images containing scanned text can be accomplished by changing the spacing between words, the spacing between lines, and the symbol fonts. Direct sequence spread spectrum has been employed to hide data [9]. After choosing a key to generate a pseudo-random carrier function, the information to be hidden is then modulated and added to the original image. Some schemes interpret information hiding
as pattern overlaying [1]. Therefore, all least significant bit methods can be associated with patterns containing high frequency content, while spread spectrum techniques use patterns with specific structures. Patterns generated by a linear combination of some basis functions have been proposed. The coefficients in the linear combination representation are directly related to the hidden content.

Stereographic projection is often used to represent three-dimensional objects [10-13]. Two views of a scene, one for the right eye and one for the left eye, generated from different viewing positions by a camera pair are needed to derive the depth of the scene. The different location of objects projected on the eye’s retina and the convergence angles of the optical axes of the eyes are two principal binocular cues extracted from the stereo image pairs. The stereo pairs are characterized by a horizontal offset along the projection plane. The amount of positional disparity between the matching pixels in the left and right image pairs is a function of the object depth, the focal length of the lens and the distance between the lens’ focal planes. A method for displaying objects with three-dimensional views is to reflect a raster image from a vibrating flexible mirror. The vibrations of the mirror are synchronized with the display of the scene on the screen. As the mirror vibrates, the focal length varies so that each point in the scene is projected to a position corresponding to its depth.

The motivation for employing the paradigm of generating stereo pairs to embed data lies on the observation that these two matching stereo images are identical in the pixel values, and only deviate slightly in terms of the pixel location. One of the stereo pairs is chosen from a common database as the host image. The other image holding embedding data is termed as the counterfeit image and the information to be hidden is taken as the scene depth. Given the hidden information, the focal length, and the distance between the lens’ focal plane, the matching pixel coordinates between the stereo pairs can be derived. Since one of the stereo pairs is selected first, the other stereo image is then simply colored by copying the intensity value of the matching pixels in the original host image. Due to the locality property typical present in the image contents, these two stereo images shall resemble each other even in the presence of moderate positional difference and make a human observer difficult to differentiate one from another.

One of the system configurations for stereographic projection, namely, the focal length, is served as the hiding key and stored in the low order bits of the derived stereo image in the proposed scheme. The focal lengths of the lens are adjusted according to the scene depth, i.e., the data hidden, to maintain a constant horizontal offset between the two matching images formed on the projection planes for all points in the three-dimensional scene. Unlike other least significant data replacement schemes, the number of least significant bits used is not a constant, rather than determined by the unique subsequence length after the addition of embedding data. The longer the length of the unique subsequence, the fewer number of lower ordered bits employed per pixel. Since a pixel matching procedure has to be performed on the decoding side, the proposed variable-length least significant bits replacement method provides yet another layer of security. By examining the counterfeit image received, the other matching stereo pair can be retrieved from a local image database and therefore need not be transmitted. When extraction of the hidden data is desirable, the stereo pairs composing of the host and counterfeit images can be examined by following the same unique subsequence identification procedure at the transmitting side in a left-to-right, top-to-bottom scanning order. Once the matching pixel location between the stereo pair is discovered, the length for a specific unique subsequence can be determined. The value of the focal length for that specific segment distributed over the lower order bits across the constituent pixels can bereassembled. Given the matching stereo pair and the stereographic system configurations, the depth information, i.e., the hidden data, can be extracted segment by segment losslessly. The power of this approach is hinged on the pixel matching process between two stereo images. Since
the process of registering the corresponding pixels between two matching images is inherently a difficult problem, the value of the focal length is therefore not likely to be discovered.

The data hiding scheme proposed in this paper is based on the binocular fusion of the stereo pairs. To this purpose, the procedure for generating the matching stereo image for a given host image is introduced in Section 2. The data extracting operation in the decoding side given the stereo pairs and system configurations is also described. The method proposed is tested on two types of host images along with two different hidden data in Section 3. The performances in terms of the hiding capacity and the peak signal-to-noise ratio (PSNR) between the original and counterfeit images are collected. Finally, conclusions are made and future works are discussed.

2. DATA HIDING AND EXTRACTION

The binocular cues produce very strong three-dimensional depth perceptions by fusing two separate and distinct images perceived in each eye into a single image. Each image formed in the eye’s retina is a perspective projection of a three-dimensional scene. In the setting for the generation of the matching stereo images, as shown in Fig. 1, the stereo pairs are located at the focal distance \( f \) of the lenses and separated by an amount \( 2w \) between lens’ focal plane to achieve binocular fusion. The stereo image is reconstructed at a distance \( I \) from the lenses. Perspective projection of a three-dimensional point \( P(x, y, z) \) in a scene onto the \( z=0 \) plane yields the right stereo image \( H_{r} \) and the matching left image \( H_{l} \) as follows:

\[
[H_{r}] = [x \quad y \quad z \quad 1] \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 0 & -\frac{1}{f} \\
w & 0 & 0 & 1
\end{bmatrix} = \begin{bmatrix}
\frac{x + w}{\frac{y}{f} + 1} & \frac{y}{\frac{y}{f} + 1} & 0 & 1
\end{bmatrix},
\]

and

\[
[H_{l}] = [x \quad y \quad z \quad 1] \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 0 & -\frac{1}{f} \\
-w & 0 & 0 & 1
\end{bmatrix} = \begin{bmatrix}
\frac{x - w}{\frac{y}{f} + 1} & \frac{y}{\frac{y}{f} + 1} & 0 & 1
\end{bmatrix}.
\]

The \( y \)-coordinate for the stereo pairs is the same according to the above formulation. For each pixel \( P_{r}(x_{r}, y) \) in \( H_{r} \), the \( x \)-coordinate difference \( d \) between the matching pixel location \( P_{l}(x_{l}, y) \) in the left stereo image \( H_{l} \) is

\[
d = x_{l} - x_{r} = \frac{2wf}{z - f},
\]

where \( x_{r} \) and \( x_{l} \) are the \( x \)-coordinates for the projected spatial point \( P(x, y, z) \) formed on the right and left image planes, respectively. Since \( x_{r} \) the \( x \)-coordinate of the host image, \( f \) the focal length, and \( 2w \) the lens’ separation of the focal planes are given \textit{a priori}, the value of \( x_{l} \) can be derived by following the above formulation once the data to be hidden is taken as the depth value \( z \). After the \( x \)-coordinate \( x_{l} \) for the left stereo image is determined according to Equation (1), the pixel value for \( P_{l}(x_{l}, y) \) in \( H_{l} \) is set equal to \( P_{r}(x_{r}, y) \) in \( H_{r} \).
However, the $x$-coordinate difference $d$ between stereo pairs will be affected by the depth $z$, i.e., the hidden data. If $d$ is allowed to fluctuate freely according to the given $z$ values, the resulting pixel location may juxtapose one another and pixel overlapping occurs. The pixel at a latter position may shift to the front due to depth change and replaces the original occupying pixel. The pixel-overlapping scenario corresponds directly to occlusion found in binocular fusion of the stereo pairs. Only the spatial point with the shortest depth value will be displayed on the projection plane for all spatial points with the same projected coordinates. Since the pixels may overlap with each other to exclude the chance of a successful matching in the decoding phase, rules for the derivation of the horizontal offset $d$ must be established in order to facilitate the matching process in the extraction of hidden data. For each hidden data $z$, the value of the focal length $f$ is adjusted to maintain a $d$ value to avoid pixel overlapping from occurring. This bears an analogy to use cameras with adjustable focal lengths to examine different portions of the objects in the three-dimensional scene. The purpose is to exclude occlusion by maintaining a displacement progressing in only one direction to expedite the stereo matching in the decoding ends. Since the focal length is a function of the data hidden, the value of the focal length is stored in the lower order bits of the stereo counterfeit image formed according to the following formula:

$$f = \frac{dz}{2w + d}, \quad (2)$$

where the hidden data $z \in \mathbb{N}$, $w$ a constant separation between lens’ focal plane in the system setup, and a pre-selected displacement $d$, $d \in \mathbb{N}$, between matching pixels in the stereo pairs.

Since the value of the focal length $f$ is generally a floating number calculated from Equation (2), the value $\hat{f}$ actually stored and latter retrieved from the lower order bits represents an integer estimate of $f$ due to the limited precision representable for the fixed number of bits allocated, i.e.,

$$\hat{f} = \left[ f + \frac{1}{2} \right] = \left[ \frac{dz}{2w + d} + \frac{1}{2} \right], \quad (3)$$

where $\left[ \cdot \right]$ is the Gaussian notation which rounds a number to the largest integer smaller than or equal to itself, i.e., $\left[ x \right] = n$, where $n$ is the largest integer for $n \leq x$. Given the estimate $\hat{f}$ of the focal length, the horizontal offset $d$, and the separation between the lens’ focal plane
2w, the data hidden can be restored on the decoding side by employing the formula below:

\[ \hat{z} = \hat{f} \frac{(2w + d)}{d} \quad (4) \]

Since \( \hat{f} \) is only an integer estimate of \( f \), the \( \hat{z} \), obtained from the above formulation is also an approximation of the real hidden data \( z \). We will show next that if the stereoscopic system configurations can be carefully chosen, the estimate \( \hat{z} \) reconstructed is equal to the hidden data \( z \) after rounding to the nearest integer, i.e., \([\hat{z} + 1/2] = z\).

\[
\begin{align*}
-\frac{1}{2} \leq z - \hat{z} < \frac{1}{2} & \Leftrightarrow -\frac{1}{2} \leq \frac{(2w + d)}{d} f - \frac{(2w + d)}{d} \hat{f} < \frac{1}{2} \\
& \Leftrightarrow -\frac{d}{2(2w + d)} \leq f - \hat{f} < \frac{d}{2(2w + d)}. 
\end{align*}
\]

Equation (5) states that the horizontal offset \( d \) and the separation of the lens’ focal plane \( 2w \) shall be adjusted such that \( d/2(2w + d) \) is greater than the rounding error relating to the value of the focal length to avoid data discrepancy after the rounding operation on the recovered data \( \hat{z} \).

In order to increase the power for data hiding, the proposed method employs a unique subsequence identification procedure using variable-length unique pixel pattern to identify the beginning and ending of the pixels sharing the same focal length. A unique subsequence is obtained by examining the pixel values one by one in the left-to-right, top-to-bottom fashion for the host and counterfeit images, respectively. If a vector containing continuous pixel values is unique among all possible subsequences formed, the specific pixel pattern is a unique subsequence. The lower order bits of the pixels composing a unique subsequence in the host image are altered to store the value of the focal length for testing. If the matching pixels in the counterfeit image remain a unique subsequence after the addition of the value of the focal length, a matching pair of unique subsequences are formed. Otherwise, the length of the original unique subsequence in the host image is extended to include one more pixel for examining the uniqueness of the new segment after inserting focal length information. The process reiterates until the unique subsequence pairs are identified before and after the altering of low order bits to accommodate the value of the focal length.

Let \( \hat{S}^H \) be the linear sequence formed by scanning the original host image \( H \) in the left-to-right, top-to-bottom order. A sequence with length \( N \), \( \hat{S}^H_N = [P_1, P_2, \ldots, P_N] \), is a vector composed of \( N \) succeeding pixel values in \( \hat{S}^H \). The pixels in the image \( H \) can be decomposed by a mutually exclusive exhaustive sequences containing \( l \) segments, i.e.,

\[ \hat{S}^H_N \ominus \hat{S}^H_0 \ominus \ldots \ominus \hat{S}^H_l = \bar{S}^H, \]  

where \( \ominus \) represents the concatenation of sequences. The concatenation of these non-overlapping \( l \) sequences segment by segment is equivalent to the original linear sequence composed of the row-wise image scanning. A unique subsequence \( \hat{U}^H_n \) of the image \( H \) is itself a sequence with length \( n \) and not a subset of any mutually exclusive exhaustive sequences \( \hat{S}^H_n \) formed after excluding \( \hat{U}^H_n \) from \( \bar{S}^H \), i.e.,

\[ \hat{U}^H_n \subseteq \bar{S}^H, \text{ and } \hat{U}^H_n \not\subseteq \hat{S}^H_n. \]

A single piece of data is hidden in every unique subsequence constructed and the corresponding value of the focal length is distributed evenly through the lower order bits of the constituent pixels. Let the unique subsequence \( \hat{U}^H_n \) contain succeeding \( n \) pixels, \( P_1, P_2, \ldots, P_n \). The number of bits \( b_j \) composing the focal length value \( f \) is distributed throughout the lower order \( a_n, a_n, \ldots, a_n \) bits of \( P_1, P_2, \ldots, P_n \), respectively, according to
the following formulation:

\[
P_1: a_i = \left\lfloor \frac{b_i}{n} \right\rfloor,
\]

\[
P_2: a_z = \left\lfloor \frac{b_z - a_z}{n-1} \right\rfloor,
\]

\[
P_n: a_u = \left\lfloor \frac{b_u - \sum_{i=1}^{n-1} a_i}{1} \right\rfloor,
\]

where \( \left\lfloor \cdot \right\rfloor \) is the ceiling function which maps a number to the smallest integer larger than or equal to itself, i.e., \( \left\lfloor x \right\rfloor = n \), where \( n \) is the smallest integer for \( x \leq n \). For example, if the number of bits allocated for \( f \) is 8 and the length of the unique subsequence \( n \) is 3, then the lower order three bits of the first and second pixels and the lower order two bits of the third pixel in the unique subsequence will be replaced by the bit values of \( f \). The rest of the higher order bits for the constituent pixels in \( \tilde{U}^m \) remain unchanged.

After the procedures for identifying unique subsequence in the host image and storing the focal length value in the corresponding pixels are delineated, we will then proceed with the construction of the matching unique subsequences in the counterfeit image on the encoding side. At the beginning, the linear sequence \( \tilde{S}^c \) formed by the row-wise scanning of the counterfeit image \( C \) is an empty vector, i.e., \( \tilde{S}^c = \Phi \). Assume the original unique subsequence \( \tilde{U}_n^H \) after the distribution of focal length in the lower order bits of the constituent \( n \) pixels is \( \tilde{U}_n^H \). The pattern of \( \tilde{U}_n^H \) is re-examined for uniqueness property. If \( \tilde{U}_n^H \) remains unique among all possible subsequences of \( \tilde{S}^c \) constructed so far after the addition of the corresponding focal length values, i.e., for \( \forall N, \tilde{S}^c_N \subseteq \tilde{S}^c, \tilde{U}_n^H \nsubseteq \tilde{S}^c_N \), then \( \tilde{U}_n^H \) must remain a unique subsequence after extending the sequence \( \tilde{S}^c \) by concatenating with \( \tilde{U}_n^H \); \( \tilde{U}_n^H \) and \( \tilde{U}_n^H \) become the matching unique subsequence pairs in the stereo image pairs. The unique subsequence \( \tilde{U}_n^H \) is shifted \( d \) pixels from its original location and then concatenated with \( \tilde{S}^c \), i.e., \( \tilde{S}^c = \tilde{S}^c \oplus \tilde{U}_n^H \). However, if \( \tilde{U}_n^H \) loses its uniqueness after changing the lower order bits, a succeeding pixel in the host image \( H \) is added to the original unique subsequence \( \tilde{U}_n^H \), denoted as \( \tilde{U}_n^H \). Since the concatenation of a unique subsequence with a new pixel is also a unique subsequence, the composing bits of the focal length is re-distributed for the new unique subsequence \( \tilde{U}_n^H \) formed. After changing the lower order bits for the pixels contained in \( \tilde{U}_n^H \), according to Equation (6), the uniqueness of the \( \tilde{U}_n^H \) is examined and the whole process re-iterates until the unique subsequence pairs in both the original and counterfeit images are determined. After all new unique subsequences \( \tilde{U}_n^H \) and the corresponding \( \tilde{U}_n^H \) are determined, the original host image \( H \) and the counterfeit image \( C \) can be similarly decomposed into mutually exclusive exhaustive sequences by the matching unique subsequence pairs.

\[
\tilde{U}^H_{\cap} \oplus \tilde{U}^H_{\cap} \oplus \ldots \oplus \tilde{U}^H_{\cap} = \tilde{S}^c, \quad \cap \tilde{U}^H_{\cap} = \Phi, \quad \text{and} \quad \tilde{U}^H_{\cap} \oplus \tilde{U}^H_{\cap} \oplus \ldots \oplus \tilde{U}^H_{\cap} = \tilde{S}^c, \quad \cap \tilde{U}^H_{\cap} = \Phi.
\]

The matching unique subsequence pairs \( \tilde{U}^H_{\cap} \) and \( \tilde{U}^H_{\cap} \) share the same higher order bits and deviate from each other in the lower order bits altered by the addition of the focal length value.
The counterfeit image $C$ is constructed by placing each unique subsequence $\tilde{U}_N^u$ into the proper position, with displacement $d$ from its matching $\tilde{U}_N^h$. The pixels on the image plane of the counterfeit stereo pair not occupied by $\tilde{U}_N^u$ are filled with the original pixel values in the host image in the corresponding position. These bits representing the focal length can be re-assembled once the length of the unique subsequence is discovered to derive the value of the hidden data in the latter decoding stage.

The pixels of the stereo pairs are partitioned into segments of matching unique subsequence. Each unique subsequence $\tilde{U}_N^u$ in the host image corresponds to one and only one $\tilde{U}_N^c$ in the counterfeit image. By identifying the position of the corresponding unique patterns $\tilde{U}_N^u$ in the host image sequence $\tilde{S}^u$ and $\tilde{U}_N^c$ in counterfeit image sequence $\tilde{S}^c$, the relative displacement $d$, the length of the unique subsequence, and the focal length can be determined. On the encoding side, the focal length $f$ is determined for each data $z$ to be hidden according to Equation (2) by examining the $d$ value to avoid pixel overlapping. The ensemble of pixels forming the unique subsequence is shifted $d$ units in unison and the corresponding bits for the focal length is distributed evenly in the lower order digits of the constituent pixels. Therefore, the original host image and the counterfeit one will have differences both in the pixel gray level and location. The decomposition of the stereo pairs into segments of unique subsequence guarantees the success of latter matching process. The value of the focal length stored separately in the variable-length, instead of fixed-length, segment makes this hiding scheme even harder to detect. The length of the segment can be adjusted to yield desired levels of capacity since a unique subsequence concatenated with other additional pixels remains a unique segment. A shorter segment length increases the capacity by allowing more data to be hidden at the price of lower fidelity in the stereo image formed. On the other hand, a longer subsequence admits the same number of focal length bits to be distributed over larger pixel set to increase signal-to-noise ratio, while sacrificing the capacity in return.

On the decoding side, the data hidden is extracted by matching the stereo images, one from the model database and the other calculated and stored previously, segment by segment. Since each segment is composed of non-overlapping unique subsequence, each segment in the stereo pairs can be matched one by one. A matching unique sequence pairs can be identified by examining the contents of $\tilde{S}^u$ and $\tilde{S}^c$. The matching unique sequence pairs $\tilde{U}_N^u$ and $\tilde{U}_N^c$, $\tilde{U}_N^u \subseteq \tilde{S}^u$ and $\tilde{U}_N^c \subseteq \tilde{S}^c$, have identical segment length and share the same higher order bits. The segment displacement $d$ can be easily derived from two matching subsequences. Inside each segment, the value of focal length $f$ distributed in the lower-order bits is reassembled. Given the displacement $d$, the focal length $f$ and the constant lens separation of the focal plane $2w$, the hidden data can be restored following from Equations (4) and (5):

$$z = \left[ f + \frac{2wf}{d} \right]$$

Fig. 2 is an illustration of the data hiding and extraction process. The host image serving as one of the stereo pairs is selected from a database first. The pixel values and the corresponding gray level diagram for the host image are shown on the upper right corner. The host image is inputed into the unique subsequence decomposition module for partitioning the pixels into segments containing unique pixel pattern. For reasons of simplicity, only pixels on the same row and will not be shifted out of the row boundary in the counterfeit image are considered as candidates for the unique subsequences. The sequences $[16, 16, 36, 8, 96, 96, 64, 64, 100, 100] and [100, 100, 101]$ are identified as unique. Under the constraint that the displacement between matching segments shall not overlap with other unique patterns, the
corresponding focal length $f$ is calculated. The bits of focal length are evenly distributed among the constituent pixels for the unique subsequence in the counterfeit image currently considered. The data hiding procedure proceeds until all data are embedded or unique patterns are exhausted. In our example, the matching unique subsequence pairs in the host and counterfeit images include $\{[16, 16]->[19, 18]\}, \{[36, 8]->[33, 4]\}, \{[96, 96]->[98, 99]\}, \{[64, 64]->[67, 68]\}, \{[100, 100]->[97, 105]\}$ and $\{[100, 100, 100]->[102, 98, 100]\}$. The counterfeit image containing embedded focal length data is stored or transmitted to the decoding side. The counterfeit image is compared with the original host image in the decoding ends for the extraction of hidden data. The pixel patterns on these two stereo pairs are matched pixel by pixel in the left-to-right, up-to-bottom fashion. Once the unique subsequence matching is reached, the length of that specific subsequence and the relative horizontal offset can be derived. The value of the focal length can be reassembled by acquiring the subsequence length. Given the focal length $f$, the displacement between matching segments $d$, and the constant separation between the stereo image plane $2w$, the hidden data $z$ is extracted losslessly by following the paradigm for calculating the depth field from the stereographic projections.

$$f = \frac{dz}{2w+d}$$

$$z = f + \frac{2fw}{d}$$

$$(50,20,35,52,25,200)$$

Fig. 2 Flow diagram for the data hiding and extraction process.

3. EXPERIMENTAL RESULTS

Computer simulation is performed using the approach described in the previous section to demonstrate the feasibility and efficiency of the proposed algorithm. Two standard images,
Lena and F16, with a resolution of 128x128 pixels and a depth of 8 bits are employed as the original host images, as shown in Fig. 3 (a) and (b). Two test images serving as the data to be hidden are presented in Fig. 4 (a) and (b). The distance $w$ between two lens’ focal plane is set to a constant value of 2.

Fig. 3 Host image (a) Lena, (b) F16.

Fig. 4 Image data to be hidden (a) Lena, (b) F16.

Figs. 5 (a) and (b) are the counterfeit images obtained after hiding Fig. 4 (a) in the host images Fig. 3 (a) and (b), respectively. Figs. 5 (c) and (d) are the stereo images corresponding to embed Fig. 4 (b) in host images Fig. 3 (a) and (b). The corresponding hiding capacity and $PSNR$ for both the host image and data embedded are tabulated in Table 1. The host image $PSNR$ is obtained by comparing the difference between the host image and the counterfeit image, while the embedding data $PSNR$ is derived from calculating the difference between the original hiding data and the data retrieved.

Fig. 5 Hiding result. (a) Fig. 4 (a) hides in Fig. 3 (a), (b) Fig. 4 (a) hides in Fig. 3 (b), (c) Fig. 4 (b) hides in Fig. 3 (a), (c) Fig. 4 (b) hides in Fig. 3 (b).

<table>
<thead>
<tr>
<th></th>
<th>Hiding Capacity (data bits/total bits)</th>
<th>Host Image $PSNR$ (dB)</th>
<th>Embedding Data $PSNR$ (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Host Image</td>
<td>0.369</td>
<td>35.6</td>
<td>31.1</td>
</tr>
<tr>
<td>Embedding Image</td>
<td>0.355</td>
<td>36.7</td>
<td>31.8</td>
</tr>
<tr>
<td>Host Image</td>
<td>0.355</td>
<td>36.7</td>
<td>31.8</td>
</tr>
<tr>
<td>Embedding Image</td>
<td>0.369</td>
<td>35.6</td>
<td>31.1</td>
</tr>
<tr>
<td>Host Image</td>
<td>Embedding Image</td>
<td>PSNR</td>
<td>PSNR</td>
</tr>
<tr>
<td>------------</td>
<td>----------------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Fig. 3 (a)</td>
<td>Fig. 4 (b)</td>
<td>0.369</td>
<td>35.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.355</td>
<td>36.5</td>
</tr>
</tbody>
</table>

Table 1 Data hiding capacity, PSNR between the host and counterfeit images, and the PSNR for the original hiding data and the data extracted.

4. CONCLUSIONS

A new data hiding algorithm employing the methodology of the binocular fusion of stereo image pairs is introduced. The embedding data are modeled as the depth field in a three-dimensional scene and projected by a pair of camera lenses. One of the stereo pairs is the original host image and the other is the counterfeit image derived from the embedding data, the focal length of cameras and the separation of the camera pairs. The performance of this novel approach through different types of host and embedding data shows good performance in measures relevant to data hiding capacity and the PSNR between the host and counterfeit images. The proposed data hiding algorithm requires only linear stereographic transformation of the host image to the corresponding counterfeit image. This desirable property makes the real-time data hiding and extraction feasible. Also, the system performance in terms of data hiding capacity and the PSNR between the stereo pairs can be adjusted to meet the demands of specific application needs.

REFERENCES