Stereo Image Watermarking Using Random Least Significant Bit and Arnold Transform

Osama Hosam
City of Scientific Researches and Technology Applications, Alexandria, Egypt 21934
Email: mohandesosama@yahoo.com

Abstract – Security of transferring data through channels has lots of concern especially if the transferred data is important. In stereo images, the scene is reconstructed from pair of images; the resulting is the 3D information which in some applications needs to be transferred through insecure channel. The security is important to protect the data from eavesdropping. We have proposed novel technique to secure the transferring of the 3D data by watermarking the stereo images. The watermark will be the 3D data. First the image will be scrambled by Arnold transform, then the 3D data (Watermark) will be embedded into the stereo images by Random Least Significant Bit watermarking. The watermark will be dispersed over the image. Results showed that our technique successfully protected the 3D when transferred through insecure channel.

Keywords – Stereo Image watermarking, Disparity estimation, Correspondence, Stereo Reconstruction

1. Introduction

Large contents of multimedia applications are distributed through the Internet. If there is no procedure to control their copyright and ownership, it will be easily copied and forged. Stereo watermarking techniques helped to keep the ownership of the documents and enabled network users to transfer data without the fear of illegal copying or hacking.

Multiple applications relied on using images to extract the third dimension. Approaches for detecting the third dimension of an image are shape from shading [1], shape from texture [2], shape from motion [3], and shape from stereo [4]. However if it is needed to transfer the 3D data of stereo images, it will be transferred through insecure channel, Figure 1. This will expose the data to be hacked or stolen in case of eavesdropping. To overcome this problem a verity of algorithms has been proposed in literature.

A blind multiple watermarking schemes were proposed [5] to deal with the content protection problem of DIBR 3D images. An object-oriented method for stereo images watermarking has been proposed in [6]. Their scheme has relied on the depth extraction of stereo images to embed the watermark. They have embedded the watermark in wavelet domain by using the quantization index modulation method.

Two different stereo image watermarking schemes has been proposed in [7] they have used the disparity map and DCT. The watermark data is embedded into the right image of the stereo pair in the frequency domain by using DCT and the disparity between the left and right stereo images is extracted. Then the disparity data and the left image are transferred together through the communication channel. When received, the watermarked right image is reconstructed from the received left image and the disparity data through the adaptive matching algorithm. Then the watermark is extracted from the right image. The same authors proposed the same technique but with DWT in [8].

Stereo-image coding algorithm using digital watermarking in fractional Fourier Transform (FrFT) and singular value decomposition (SVD) has be proposed in [9]. For the purpose of the security, the original (left stereo) image has been degraded and watermark (right disparity map) is embedded in the degraded image. This watermarked degraded stereo image is processed in an insecure channel. At the receiver's end, both the watermarked image (left stereo image) and watermark images are found by the decoding process.

The same procedure in [9] has been applied in [10, 11] but with using Arnold transform [10] to degrade the host image. Also they applied real coded genetic algorithm (RCGA) to estimate the optimal order of Arnold transform and the strength of the watermark to fulfill the required security and robustness. In [11] the host image is degraded by using ZIG-ZAG sequence then the watermark is embedded.
by using wavelet decomposition and singular value decomposition, the watermark is optimized by using real coded genetic algorithm.

The estimated disparity map in the current stereo watermarking approaches contains mismatches and the security is still vulnerable. The disparity estimation is done in one level with applying the wavelet decomposition which is still not enough to estimate an accurate disparity map. Also, the security can be breached by applying the same sequence of watermark embedding on the host image to extract the watermark. In our approach, we have enhanced stereo watermarking approaches in two ways.

First, the disparity estimation is enhanced by applying two levels of correspondence, the features of the stereo images are matched then a dense disparity map is obtained by applying a Wavelet based matching. Second, we have used a random LSB method combined with a key after degrading the host image by using Arnold transform. The host image is degraded and the watermark is embedded “Randomly” by dispersing it all over the host image, this procedure makes it impossible for any hacker to estimate the contents of the image or extract the watermark. In addition the watermark can’t be extracted unless the receiver has the watermarking key.

In section 2 we will show our disparity estimation algorithm which done in two levels, Feature based matching and Wavelet based matching. In section 3 we will show how we enhanced the stereo watermarking algorithms by applying the Random LSB watermarking. In section 4 we will show our experimental results. In section 5 we will show our conclusion.

2. Disparity Map Estimation

The disparity for the pair of stereo images is done in two steps; the first step is to extract the feature of the pair of images and then compare these features together, this step is called Feature-based matching [12]. The comparison is done according to specific properties for each feature. The second step is Wavelet-based matching, in this step we are going to make dense matching by comparing the pair of images window by window leading to a more accurate matching. The overall algorithm of disparity estimation is shown in Figure 2.

2.1. Feature Based Matching

The features will be extracted using the Histogram segmentation. The features which will be extracted from both the right and the left images will be region segments; it will be extracted as follow: Histogram segmentation [13] can be viewed as an operation that involves tests against a function T of the form

\[ T = T[x, y, p(x, y), f(x, y)] \] (1)

where \( f(x, y) \) is the gray level of the point \((x, y)\) and \( p(x, y) \) denotes some local property of this point. The Histogram of the left and right images is obtained then three threshold values will be selected in the Histogram that will divide the image into four groups \( g1, g2, g3, \) and \( g4 \) each group contains different gray level region segments [14]. The proposed histogram segmentation can be defined as,

\[
\text{Pixl}(x,y) = \begin{cases} 
  g1 & \text{if } 0 < f(x,y) \leq T1 \\
  g2 & \text{if } T1 < f(x,y) \leq T2 \\
  g3 & \text{if } T2 < f(x,y) \leq T3 \\
  g4 & \text{if } T3 < f(x,y) \leq 255 
\end{cases}
\] (2)

For each group a series of (low, medium and high) resolution images will be created, which is the multi-resolution images for each group. It is created by reduction in size by a factor of two using Gaussian convolution filter \( h(x) \) [15].

\[ h(x) = \sqrt{2\pi\sigma^2}e^{-\frac{x^2}{2\sigma^2}} \] (3)

where \( \sigma \) is the standard deviation of the Gaussian curve. A binary map for each of multi-resolution images will indicate, for each pixel, whether it belongs to the group or not, as shown by equation (4).

\[
g(x, y) = \begin{cases} 
  1 & \text{if } f(x,y) > T \\
  0 & \text{if } f(x,y) \leq T.
\end{cases}
\] (4)

Thus the pixels labeled 1 correspond to the region segment, whereas pixels labeled 0 correspond to the background. Finally the open operator of the morphology filter will be applied on the low resolution images for each group to remove the small region segments which may incur errors.

The region segments as the feature elements will be used to get the disparity map (it is not the final disparity map). Using the low resolution images for each group the properties for each region will be obtained for the left and right images then the correspondence between regions will be done, finally the disparity map will be obtained.

The properties for each region [16] will be:

- Centroid: find \( x, y \) coordinates of the center of the region. The center of the region can be obtained as the half of the height and width of the region.
- \( A_1 \): can be calculated by counting the number of pixels in the region

\[ A_i = \sum_{r=0}^{N_x} \sum_{c=0}^{N_y} I_i(r,c). \] (5)

where \( A_i \) is the area of the region \( i \), and \( r, c \) represent the row and column values respectively. Figure 3 shows how the
correspondence is done by using the Centroid for each region.

Perimeter, $p$ is obtained by performing edge detection and counting the “1” pixels.

Thinness ratio, $T$: has a maximum value of 1, corresponding to a circle, and decreases as object gets thinner or perimeter gets more convoluted:

$$T = 4\pi \left( \frac{A}{p^2} \right)$$

Irregularity or compactness ratio, $1/T$, reciprocal of the thinness ratio.

Aspect ratio, also called elongation or eccentricity, ratio of bounding box:

$$\text{Aspect Ratio} = \frac{c_{\text{max}} - c_{\text{min}} + 1}{r_{\text{max}} - r_{\text{min}} + 1}$$

There are some advantages of estimating the disparity of stereo images by using wavelet representation
- The edge information like the length and orientation of lines which are available in wavelet domain may be used to enhance the disparity estimation.
- We are going to use the image after applying wavelet decomposition, this will reduce the image size significantly and save some bits when transmit the disparity map.
- Using the coarse to fine estimation in the multi-resolution wavelet representation, the disparity will be more efficiently estimated in the wavelet domain.

Our main aim is to generate a watermark image by estimating the disparity-image. In this way, we can use this disparity-image as the watermark image. The main advantage is that the computational cost reduces to one fourth in stereo matching.

Let $I_l, I_r$ represent the left and right stereo images respectively. $\{A_l, D_l, i=i, 2\}$ and $\{A_r, D_r, i=i, 2\}$ represent their 1-level wavelet decomposition. For each pixel in the left image $A_l$, the corresponding pixel in the right image is found and then drawing a fixed length window around that pixel and compare it with the corresponding pixel. This type of convolution is done through the horizontal scanning line between both images, also not all the corresponding scan line pixels will be done; only the pixels lie inside the corresponding feature taken form the Feature based matching. The measure which will be used is the SSD (Sum of Squared Deviations) which quantifies the difference between intensity patterns:

$$C = \sum_{(x,y)} \left[ A_l(x+\xi, y+\eta) - A_l(x+d+\xi, y+\eta) \right]^2$$

The disparity estimate for a pixel $x,y$ is the one which minimizes SSD error:

$$d(x,y) = \arg \min_{x',y'} C(x,y,d)$$

The comparison will be done window by window; SSD will be calculated by calculating the difference between the current window in the left image and all windows on the right image which lie in the corresponding scan line and region. The candidate window will be the window which has the minimum SSD error.

3. Watermark Embedding and Extraction
When transferring the watermarked image into a secure channel, the watermarked image should be secured. We have used the concept of image degradation in our algorithm, as an example the degradation by using the ZIG-ZAG degradation sequence [11]. We have used Arnold Transform [17] in our algorithm to scramble and degrade the host image.

First the left image – The left stereo image will be the host image - will be degraded by applying the Arnold transform, and then the algorithm of Random LSB will be applied to the degraded image. The degraded watermarked image will be safely transferred through a secured channel.

When the degraded image is received by an authorized receiver, it will be used to extract the embedded watermark. Also the original image can be restored by applying the inverse Arnold transform which restores the left stereo image to its original state. The proposed watermark embedding and extraction algorithm is shown in Figure. 4.
The Arnold transform is added to the watermarking phase to make it impossible for any hacker to know the contents of the host image or extract its 3D information.

3.1. Arnold Transform

Let \( N \times N \) be the size of the original image \( I \), \( N \) is the dimension of the watermark image. To enhance the security of our system and increase the imperceptibility we process the original image with Arnold Transform to obtain the scrambled image \( I' \). Arnold transform scrambles the original image by splicing and clipping that realign the image pixels. The Arnold transform \([18, 19]\) can be described as

\[
\begin{bmatrix}
x' \\
y'
\end{bmatrix} = \begin{bmatrix}1 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix}x \\
y\end{bmatrix} \text{ (mod } N\text{)}
\]

(10)

where \(x, y\) are the coordinates of the pixels in the original image, \(x', y'\) are the pixel positions of the scrambled image. The transform changes the pixel positions several times. A scrambled image can be generated as follow

\[
P_{x,y}^{T+1} = A P_{x,y}^T \text{ (mod } N\text{)}
\]

(11)

where \(A P_{x,y}^T\) and \(P_{x,y}^{T+1}\) are the pixel of the original image and the degraded image respectively. \(A\) is the Arnold transform.

3.2. Random LSB Watermarking

The main idea of LSB watermark embedding is that precision in many image formats is greater than that perceivable by average human vision Therefore; an altered image with slight variations in its colors will be indistinguishable from the original by a human being, just by looking at it. By using the least significant bits of the pixels' color data to store the hidden message, the image itself is seemed unaltered.

A Random LSB embedding algorithm will be used, in which the secret data are spread out among the image data in a seemingly random manner. This can be achieved if both the sender and receiver having the same secret key or share a secure key. This key can be used to generate pseudorandom numbers, which will help extracting the secret image by defining the place and the order in which the secret data is laid out. The advantage of that method is that it incorporates some cryptography concepts that diffuse the secured data. However, it goes beyond just making it difficult for an attacker knows that there is a secret message. It also makes it harder to determine that there was a secret message in the first place. The reason is because the randomness makes the embedded message seem more like noise statistically than in the straight forward embedding method.

The combination of Arnold transform and random LSB embedding prohibited steganalysis algorithms to detect the secured data.

4. Experimental results

In this section we are going to introduce the image acquisition techniques and devices that we have used to collect our dataset and then we present our results for the proposed disparity estimation algorithm and the Random LSB stereo image watermarking technique.

4.1. Image Acquisition Techniques

We have used the Object registration device Figure. 5(a) to collect most of our dataset. The Object Registration is a device used to take a stereo pair of an object to be reconstructed into a 3D model. We can take more than one image for the same view. By identifying the zoom properties for each camera and specifying the distance between the pair of cameras we can easily identify the whole parameters which are needed to take a prefect stereo pair.

![Figure 5. The image acquisition techniques, (a) The Object Registration device. Source: City of Scientific Researches and Technology Applications, Informatics Research Institute, Alexandria, Egypt (b) Aircraft Stereo images](image)

Here we can use one camera to take our stereo pair instead of two. The idea is to take the first picture of the view then we move the camera using the moving parts of the object reg. – notice the arrows in Figure. 5 (a). Then the camera position is changed and we can easily take another image of the same view.

In addition, we have used stereo images taken by an Aircraft. Stereo images from an Aircraft are pair of aerial photos taken sequentially. A camera on board an aircraft takes pictures of the Earth at different times and thus from different positions, Figure. 5 (b)

4.2. Disparity Estimation

Disparity is estimated in two levels; the first level is Feature based matching. The features are extracted as regions and the properties for each region will be calculated, then a correspondence between the left and right images will be calculated. The second level is the wavelet base level in which the correspondence is done pixel by pixel. Due to the two levels approach we have reduced the correspondence mismatches to its minimum. In Tab. 1 we have presented how our algorithm enhances the matching process, almost all the available disparity estimation algorithms have done the correspondence in one level but in our algorithm we have applied two levels of matching.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Number of matching levels</th>
<th>Mismatches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantization and Modulation [6]</td>
<td>1 level</td>
<td>23 %</td>
</tr>
<tr>
<td>DCT based [7]</td>
<td>1 level</td>
<td>21 %</td>
</tr>
<tr>
<td>DWT based [8]</td>
<td>1 level</td>
<td>29 %</td>
</tr>
<tr>
<td>Fractioanl Fourier transform (FrFT) [9]</td>
<td>1 level</td>
<td>19 %</td>
</tr>
<tr>
<td>Genetic Algorithm (GA) [10]</td>
<td>1 level</td>
<td>16 %</td>
</tr>
<tr>
<td>Our Algorithm</td>
<td>2 levels</td>
<td>4 %</td>
</tr>
</tbody>
</table>

Table 1. A comparison between our algorithm and the related algorithms with respect to the accuracy of correspondence.
The mismatches can occur if a feature in the left image is assigned to a feature in the right image which is not its correct corresponding feature. Also as mentioned in [4], the increasing of occluded regions will affect the accuracy of matching. The occluded regions are the regions which appear in one image and disappear into the other. In Feature based matching, we have created multi-resolution images by Gaussian Pyramids.

We have applied the correspondence on a lower resolution image, since we will need to compare a lower resolution image when making correspondence by applying wavelet decomposition. For example the Pentagon image is 512 x 512, we will create multi-resolution images as (512 x 512, 256 x 256, 128 x 128), also we will apply wavelet decomposition on the original Pentagon image to create 256 x 256 image. So in the first and the second levels, the correspondence will be done on the 256 x 256 images. This way the embedded watermark (disparity map) size will be reduced to half the size of the original image.

In Figure. 6 We made a comparison between our disparity estimation method and the related work. We notice how our disparity is more accurate than the other methods. For example in Figure. 6 (b) the table is not appeared as one part, instead just one part of it appeared and the other is hidden due to the shadow of the head. In Figure. 6 (c) we notice some parts around the camera in white color - The white color represents the nearest object and the black color represents the farthest object- it appeared in the disparity map that these parts are near the camera but in fact they are deep in the image.

Building Random LSB is straightforward, which made our implementation for the proposed algorithm simple. However in the related algorithms they need to implement GA, DCT, DWT, and FFT which complicated the implementation process. The security of Random LSB stereo image watermarking is higher than the related algorithms; we achieved the lowest cost of implementation.

5. Conclusion

The process of stereo image reconstruction is enhanced by applying two levels of disparity estimation. The first level is comparing each feature in the left image with the features in the right image; the feature-based disparity is used in Wavelet based matching to make denser disparity estimation. The obtained disparity has higher quality than that of the related algorithms. A highly secure stereo image watermarking system has been implemented.

The Random LSB is applied together with a key to increase the security of the watermarking system. We have applied our technique on multiple stereo images, the results showed how the technique enhanced the quality of the extracted disparity map and the security of the watermark.

In our future work, we will move to watermarking the resulting 3D model by directly embedding data into the 3D model itself. The stereo matching process will be executed and the resulting stereo model will be subjected to watermarking process by changing some of its geometrical and topological features.
References


