Digital Image Watermarking in Regions of Interest

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Abstract

Most existing watermarking techniques embed watermarks into the entire image without taking the image content into account. For many applications, a certain portion of an image is more important than the other regions, which is often called the region of interest (ROI). In this work, we develop two wavelet-based watermarking schemes which exploit both frequency- and spatial-domain information to embed invisible and robust watermark. The first scheme requires the original image and the priori information of ROI during watermark extraction. The second scheme does not require the knowledge of the original image and ROI in the retrieval process. In addition to enforcing copyright protection on digital images, the proposed interactive ROI watermarking schemes can be used as data labeling to assist content retrieval in multimedia archiving. Experimental results show that the embedded watermark is robust against various attacks with more protection on ROI.

1. Introduction

The rapid growth of multimedia manipulation tools and wide availability of network access lead to the convenience of digital data processing, delivery and storage. Unlike traditional analog copying with which the quality of the duplicated content is degraded, powerful digial facilities can produce a large amount of perfect copies in a short period of time. This may benefit content distributors but become the nightmare of content owners, if the proper copyright protection cannot be successfully enforced. Digital watermarking has been recently proposed as a solution for prohibiting copyright infringement of multimedia data. By embedding indelible and imperceptible labels and/or signatures into various digital media, extraction of the embedded information without ambiguity can be used to identify the copyright owner or legitimate recipients to prevent these data from being illegally distributed or misused. Here, we focus on applying digital watermarking techniques to information embedding in digital imagery. Several digital image watermarking schemes have proposed [1]-[4] in recent years. We can divide the proposed watermarking schemes into two classes depending on the domain of watermark insertion: frequency- and spatial-domain watermarking methods. The former class provides better protection against signal processing attacks while the later class preserves more spatial-domain information.

Most existing watermarking techniques embed watermarks in the entire image without taking the image content into account. For many applications, a certain portion of an image is more important than others. Especially, for object-oriented images, regions that cover the main objects are of major concern to the image owner. For example, in a picture with a person appearing at the center, the image viewer usually cares more about the person than the background of the picture. The portions that attract more attention of an image viewer are called the regions of interest (ROI). It is desirable to embed robust watermarks in ROI to give them better protection. Following our previous work in [5],[6], two wavelet-based threshold adaptive watermarking schemes are proposed to embed robust and invisible watermark in ROI. For both proposed methods, the image owner selects some parts of the image as ROI to insert the watermark. The main difference between these two algorithms is that the second scheme requires no original image as a reference in retrieving the watermark. By using the combined spatial-frequency characteristics of the wavelet transform, the proposed watermarking schemes can maintain good image integrity and the embedded watermark can resist various attacks. Most importantly, ROI does receive better protection.

This paper is organized as follows. The process of constructing ROI in the transform domain is described in Section 2. The first and the second watermarking schemes are presented in Sections 3 and 4, respectively. Experimental results are shown in Section 5. Finally, concluding remarks are provided in Section 6.

2. ROI Construction in the Frequency Domain

ROI is usually selected by image owners or users in the space domain. After selecting ROI in an image, it is straightforward to embed the watermark in the space domain, i.e. modifying values of image pixels directly so that we can decide as our will on what portions of the image should be embedded with what kind of watermarks. It is worthwhile to point out that there may be different ROI in the same image depending on different applications. However, spatial-domain watermarking is vulnerable to signal processing attacks such as compression and filtering. The fragility of the spatial-domain watermark technique limits its applications to data hiding or image authentication. To achieve robust and imperceptible watermarking, we choose to cast the watermark onto significant frequency domain coefficients.

The wavelet transform is used to achieve the decorrelation of pixel values. Since the energy of most images is concentrated in the low frequency components, the hierarchical pyramid wavelet structure is used in our algorithm, where subbands are logarithmically spaced in the frequency domain (i.e. octave-band decomposition). To begin with, the image is divided into four subbands and critically sampled. Each coefficient represents a spatial area corresponding to approximately a 2×2 area of the original image. Four subbands are obtained by cascading vertical and horizontal decompositions. Three of four subbands represent the finest scale wavelet coefficients. To obtain the next coarser scale of wavelet coefficients, the lowest frequency subband is further decomposed and critically sampled. The splitting process continues until a certain final scale is reached. It has been observed that there is a spatial self-similarity between wavelet subbands. For instance, low-activity areas are expected to be identified in the coarest levels of the pyramid, and they are often replicated in finer levels at the same spatial locations. Several well-known coding algorithms, such as EZW [7] and SPIHT [8], exploit this property to achieve a high coding efficiency.

Motivated by the above observation, we can construct the ROI map in the wavelet domain from the spatial ROI map. To construct the spatial ROI map, an image owner may draw a contour around a target object to form the ROI, which can be of any shape but a closed contour. All of the pixels within the contour compose the desired ROI. If we only have one type of ROI in an image, the spatial ROI map will takes two values, one value for ROI and one value for the rest of the image. Then, we can construct the wavelet-domain ROI map from this spatial ROI map in a straightforward fashion. That is, we divide the spatial ROI map into blocks with size 2×2. In each block, if there are more than 2 points belonging to ROI, this block is set to be in ROI in the next coarse map. Three of the four finest subbands have the same map. We continue with the low-low frequency band to construct the ROI map in the next coarse level. An example is given in Fig. 1. The original image where a person is surfing on the wave is shown in Fig. 1(a). The person is marked as ROI in Fig. 1(b). The spatial ROI map is drawn in Fig. 1(c) while the wavelet domain ROI map is depicted in Fig. 1(d).

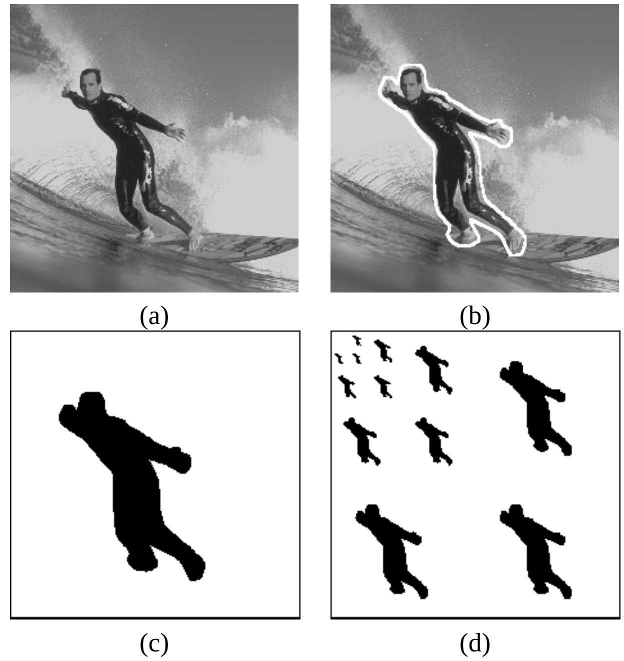


Figure 1: *(a) The original image, (b) the contour of ROI, (c) the spatial-domain ROI map, and (d) the wavelet-domain ROI map with decomposition level equal to 4.*

3. ROI Watermarking Scheme I

After the wavelet-domain ROI map is constructed, we cast the watermark signal onto siginificant wavelet coefficients with respect to this frequency ROI map. To select significant coefficients for robust watermark embedding, we examine significant subbands first by using the principle of MTWC (multi-threshold wavelet coding)[9] and, at the same time, examine the frequency ROI map to embed watermarks. The watermark is embedded and adaptively scaled by subband threshold values to maintain perceptual integrity. Significant coefficients are those with a larger magnitude. In general, these coefficients do not change a lot after signal processing and/or compression attacks. If they do change substantially, the reconstructed image will be perceptually different from the original one. The general procedure of significant coefficient selection is as follows.

1. Initialization: Set the initial threshold T_s of each subband to one half of its maximum absolute value of coefficients inside the subband. Set all coefficients un-selected.

2. Select the subband (except the DC term) with the maximum value of $\beta_s \times T_s$, where β_s is the weighting factor of subband s. For the selected subband, we examine all un-selected coefficients $C_s(xy)$ within the ROI and choose coefficients which are greater than the current threshold T_s as significant coefficients.

3. The watermark is cast in the selected significant coefficients obtained in Step 2.

4. Update the new threshold in subband s via $T_s^{new} = T_s/2$.

5. Repeat Step 2 to Step 4 until all ROI watermark symbols are cast.

ROI may not be the only region with watermark embedding. For example, ROI may only occupy a small portion of an image. To increase the robustness of the whole image to combat intentional or unintentional watermark attacks, we should insert the watermark signal to other parts of the image. Thus, after casting the watermark sequence of length L_1 onto coefficients associated with ROI, we cast another watermark sequence of length L_2 into coefficients regardless of ROI. Reset threshold T_s of each subband to one half of its maximum absolute value inside the subband. Omitting ROI in Step 2, we repeat Step 2 to Step 4 to cast the watermark onto significant coefficients chosen from remaining un-selected coefficients until we embed all the watermark symbols. The total length for embedded watermarks is equal to $L_1 + L_2$. It should be noted that the second part of watermark embedding is not restricted to regions outside ROI. If a given ROI is large, it is still possible to cast watermark into ROI during the second watermarking stage.

The formula of watermark casting is

$$C_s^{'}(xy) = C_s(xy) + \alpha\beta_s Ts W_k, \quad (1)$$

where C is the selected original coefficient, $C^{'}$ is the watermarked coefficient, T_s is the current threshold of subband s, W_k takes two values, 0.5 and -0.5, and is the kth watermark element in a watermark sequence of length $N_w = L_1 + L_2$. The watermark sequence is generated by a seed, which can be viewed as a user ID number. α and β are scaling factors. The value of α is adjustable by the user to increase (or decrease) the watermarked image fidelity and decrease (or increase) the security of watermark protection. It is chosen that $\alpha \in (0.0, 1.0]$. The parameter β_s is used to control the subband selection order. For example, a larger value of β_s in higher frequency subbands can give significant coefficients in the higher frequency components a higher priority.

For the watermark detection part, the extracted error can be written as

$$E_{s,k}^*(xy) = C_{s,k}^*(xy) - C_s(xy),$$

where C^* is the coefficient coming from the possible attacked image I^* and C_s is the coefficient of the original image I. The detection is performed by computing the similarity between C^* and C as

$$SIM(I^*, I) = \frac{\sum_{k=1}^{N_w} E_{s,k}^*(xy) \cdot E_{s,k}(xy)}{||E_{s,k}^*(xy)||||E_{s,k}(xy)||}, \quad (2)$$

where N_w is the amount of watermark symbols, $E_{s,k}(xy)$ is the original watermark and $E_{s,k}^*(xy)$ is the attacked watermark with respect to wavelet coefficient $C_s(xy)$. Note that we use the inner product of $E_{s,k}^*$ and $E_{s,k}$ normalized by their norms as the similarity measure, which measures the cosine function of the angle of two vectors. Any similarity measure less than zero is treated as zero, where these two vectors $E_{s,k}^*$ and $E_{s,k}$ are actually in the reverse direction. The maximum value of the similarity is 1 if the watermark is perfectly extracted.

Even though the pseudo-random watermark sequence cannot give a better correlation detection than the random number sequence with a normal distribution, the energy of various watermark signals can be made similar so that the integrity of the watermarked image can be maintained within a bound. Thus, watermarks generated by different seeds (or owned by different users) can have the same degree of robustness against attacks.

4. ROI Watermarking Scheme II

The second watermarking scheme is a blind watermarking scheme, which means that original image is not required in watermarking retrieval. Although the original image as well as ROI information are unknown in the retrieval process, the system can allow users to decide which portions of the image they are interested in and inform users whether these regions are embedded with watermarks or not. To make blind watermarking work, the embedding part is modified as follows. For an image of size $N \times M$, a pseudo-random number map which takes two values, 0.5 and -0.5, is made. The size of the random number map is $n \times m$ where $n \leq N$ and $m \leq M$. The larger the size of the random number map is, the better detection reponse can be achieved at the expense of a larger storage space or memory during the watermark embedding and retrieval process. Significant coefficients are selected by the same method described in Section 3. When a coefficient is selected and its coordinate is (x, y), we check the position $(x(mod)n, y(mod)m)$ on the pseudo-random number map to decide the watermark symbol.

The most difficult problem associated with blind watermarking in the wavelet domain is to identify coefficients with the embedded watermark and the embedded watermark values. The main idea of blind watermark algorithm is to truncate the selected original significant coefficients to some specified value to generate "pseudo-original" significant coefficients and then watermark signals are cast onto these "pseudo-original" coefficients to form the protected or watermarked coefficients.

Let $C_s(x, y)$ be the selected significant coefficients in the subband s with current subband threshold T_s, i.e. $T_s \leq C(x, y) < 2 \times T_s$, then the protected version of C_s is modified as

$$C^{'}_{s,k}(x, y) = sign \times \Delta_p(C_s(x, y)) + \alpha\beta_s T_s W(x, y). \quad (3)$$

where $W(x, y)$ is the watermark symbol in the location (x, y) on the pseudio-random number map, $sign$ is the sign value of $C_s(x, y)$, and the operation Δ_p is defined as

$$\Delta_p(C_s(x, y)) = (1 + 2p\alpha)T_s, \quad (4)$$

and where p is an integer between 1 and $(2\alpha)^{-1}$. The distance $DIS_{s,p}(x, y)$ between $\Delta_p(C_s(x, y))$ and $C_s(x, y)$ is defined as

$$DIS_{s,p}(x, y) = |\Delta_p(C_s(x, y)) - |C_s(x, y)|| \, .$$

Then, we can obtain p by

$$p = \arg\min_{p'} DIS_{s,p'}(x, y).$$

After p is selected, we have

$$DIS_{s,p}(x, y) \leq \alpha \times T_s.$$

During the watermark retrieval process, the user chooses a point (x_0, y_0) on the image. Then, a window of size $h \times w$ centered at (x_0, y_0) is formed as ROI for watermark detection. The blind watermark detection formula is basically similar to Equation (2) with the replacement of $E_{s,k}(x, y)$ by

$$E^*_{s,k}(x, y) = C^*_{s,k}(x, y) - sign \times \Delta_p C^*_{s,k}(x, y),$$

where Δ_p is equal to $(1 + 2p\alpha)T^*_s$, and where T^*_s is obtained from C^*.

Since T^*_s comes from the largest coefficient in subband s, and no watermark is embedded in this coefficient, T^*_s should be very close to T_s. Given the constraint $\beta_s \leq 1.0$, if the distortion on $C^{'}_{s,k}(x, y)$ is less than αT_s, then the watermark on $C_s(x, y)$ can be perfectly detected. A larger α could provide more robustness to attacks but a poorer PSNR performance in the watermarked image. Another difference between ROI schemes I and II is that the number of the extracted watermark signals in blind retrieval is much smaller than the embedding number N_w since only pixels in ROI, instead of the whole image, are selected for watermark retrieval .

In addition to copyright enforcement, the proposed interactive ROI watermarking schemes can also be used as data labeling to assist content retrieval in image databases. In image archiving, high performance data representations and structures are essential to image database management. By using traditional database indexing methods, it is not easy to index the location, size and relationships of the objects in the image. In the newly-proposed database indexing techniques, the objects are extracted by low-level feature extraction or segmentation. However, it is very difficult to achieve perfect image segmentation and image understanding methods may need to be included to improve the performance of object extraction. Related techniques of image understanding are not mature yet for object retrieval. ROI watermarking could bridge the gap between the traditional and newly-proposed indexing methods.

The interface of our database system can allow the user to choose his or her ROI from the sample image. The objects of the sample image are embedded with different watermarks that are defined in advance by the database manager. The watermark can be a number or a string, which may represent as large as a category (e.g. people, animals, transportation tools etc.) or as small as a person, a brand of car, a type of product etc. The detailed information cannot be achieved by using low-level texture extraction. Besides, the label is embedded directly into the image. It is not related with data format and requires no additional space for storing object's shape, position and class. Furthermore, the labeling is inseparable from the image data and is difficult to be removed even under compression or filtering processes. After the user marks ROI in the sample image, the database system can easily identify what kind of objects the users really want to retrieve from the image archiving. The interactive database system can provide him or her with all related candidate images to choose. What we need is a lookup table to interpret the meaning of the embedded watermark, which may stand for a hyperlink, a price tag, or some explanations of an image. Therefore, quite a few applications, e.g. advertisement, entertainment and education, etc., can be achieved by using the blind ROI watermarking scheme.

5. Experimental Results

In ROI watermarking scheme I, two kinds of embedding scenarios are compared to demonstrate its performance:

Table 1: *Peak value of the correlation response in Watermark detection with ROI and without ROI*

Global attacks	with ROI	without ROI
JPEG 5% quality	0.34	0.35
image blurring	0.27	0.21
uniform noise adding	0.48	0.48
histogram equalize	0.36	0.40
regional attacks	with ROI	without ROI
background cropping	1.00	0.25
background noise	1.00	0.68
background blurring	1.00	0.49
object sharpening	0.53	0.55

watermark embedding with and without considering ROI. For a 512×512 image shown in Fig. 1(a), we embed a watermark sequence with length $N_w = 3072$ into an image. In ROI watermarking the first 2048 watermark symbols are embedded in ROI and the last 1024 symbols are embedded according to the energy of the remaining unselected coefficients. The scaling factor α is 0.5. The ROI watermarked image is shown in Fig. 2(a). The watermark in the spatial domain, i.e. the scaled difference between the original image and the watermarked image, is demonstrated in Fig. 2(b). The correlation detection response is shown in Fig. 2(c). 1000 watermarks are tested and only the embedded watermark with ID number 450 has the peak value very close to the optimal result, 1.0. In Fig. 2(d), we crop the background of an image and refill the cropped part with a single gray level color. The detection response is shown in Fig. 2(e). The peak value, 0.87, is still much higher than others and the existence of watermark can be proved without doubt. If we embed the same watermark sequence of length 3072 without considering ROI, the correlation detection result is shown in Fig. 2(f), where the watermark is still detected because the threshold-adaptive method can successfully select significant coefficients for robust watermark embedding. However, the peak value has been significantly decreased to 0.25 owing to the severe distortion of the whole image. Comparisons between both embedding scenarios under various attacks are shown in Table. 1. The results show that watermarking with ROI outperforms watermarking without ROI in object-selective attacks.

We can also embed different watermarks into different objects in an image. A 256×512 image with 3 objects (cats) is shown in Fig. 3(a). Three different watermarks with seeds 300, 500 and 700 are embedded into these three cats, respectively. The length of the watermark sequence embedded in each object is 1024. The watermark in the spatial domain is shown in Fig. 3(b), which tells us that the

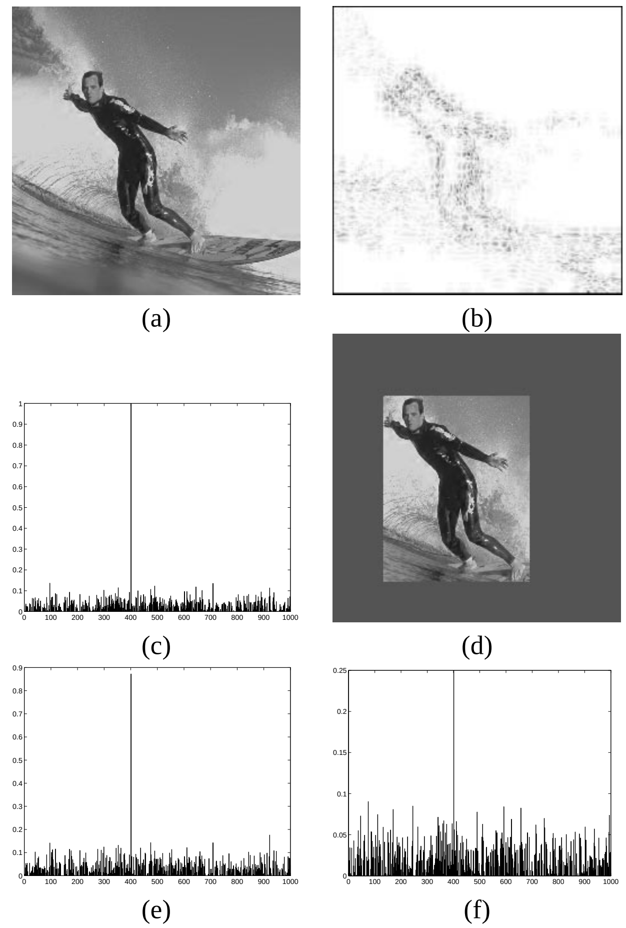
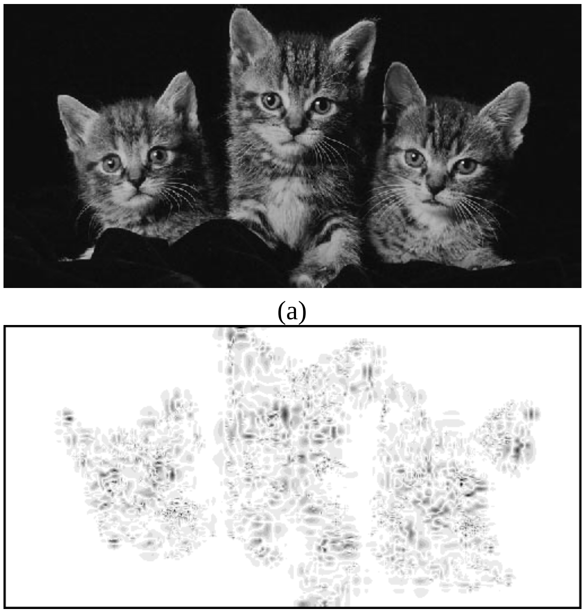


Figure 2: *(a) The ROI watermarked image, (b) watermark in the spatial domain, (c) the correlation detection response without attack, (d) the cropped ROI watermarked image, (e) the correlation detection response of the cropped ROI watermarked image, (f) the correlation detection response of the cropped watermarked image without considering ROI.*

Table 2: *Peak value of the correlation response in blind ROI watermarking under various JPEG and SPIHT compression levels.*

JPEG(quality%)	PSNR(dB)	Pt.1	Pt.2	Pt.3
100	42.95	0.99	0.94	0.96
75	33.44	0.77	0.82	0.75
50	30.89	0.65	0.62	0.64
25	29.03	0.59	0.60	0.55
SPIHT(bpp)	PSNR(dB)	Pt.1	Pt.2	Pt.3
1.0	34.56	0.69	0.82	0.76
0.7	32.09	0.57	0.61	0.57
0.5	30.31	0.60	0.59	0.58



(a)

(b)

Figure 3: *(a) The cats image with 3 objects and (b) the watermark signal in the spatial domain.*

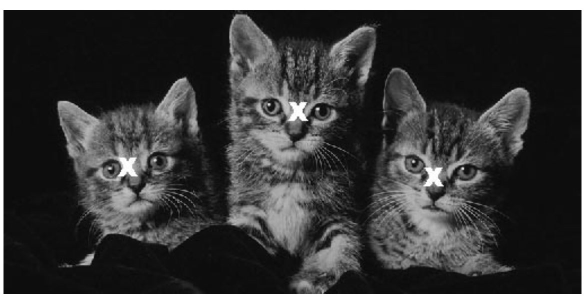


Figure 4: *Selected points on the test image. Point* 1, 2 *and* 3 *are located on the left, central and right objects, respectively. Three different watermarks are embedded in the three objects.*

three objects are embedded with watermarks and no watermark is embedded in the less siginicant background of the image. In order to detect a specific object, we construct the wavelet domain ROI map. The peak values of the correlation response by using three ROI identifying each object in an image are all close to 1. The watermark can even be extracted when some objects are cropped. We remove the two cats on two sides and leave the central cat unchanged. When we set the central object as our target, the maximum value of the correlation response is still as high as 0.98, which is almost unaffected by cropping.

In ROI watermarking scheme II, the original image is not used in the detection process. We can apply the scheme on data labeling by selecting testing points in the image for label retrieval. Whenever a point (x, y) is chosen, a block centered at (x, y) is treated as ROI for watermark retrieval. The size of the block used in our experiment is 64×64 and the retrieval number is set to be 256. The scaling number α is 0.25. We select one point on each objects shown in Fig. 4. The retrieval results under different JPEG and SPIHT compression levels are provided in Table 2. With our definition, the peak value larger than 0.5 indicates the existence of the watermark. We can clearly find that if the selected point is within the desired ROI, the ID number of the object can be identified successfully.

6. Conclusion

Two wavelet-domain threshold adaptive watermarking schemes were proposed to embed robust and invisible watermark with concerns of regions of interest (ROI) in this work. The embedded watermark is robust against various attacks and more protection is given towards ROI. The watermark retrieval can be done without resorting to the original image and the detection result is unambiguous. In addition to copyright protection, ROI watermarking schemes, combined with interactive feedback database system, can be used in a variety of applications, such as entertainment, advertisement and education, etc.

7. References

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