Introducing A New Method for Estimation Image Complexity According To Calculate Watermark Capacity

Farzin Yaghmaee, Mansour Jamzad
Sharif University of Technology, Tehran, Iran
yaghmaee@ce.sharif.edu , jamzad@sharif.edu

Abstract
One of the most important parameters in evaluating a watermarking algorithm is its capacity. In fact, capacity has a paradoxical relation with other two important parameters: image quality and robustness. Some works have been done on watermarking capacity and a few on image complexities. Most works on watermarking capacity is based on information theory and the capacity values which are calculated based on these methods are very tolerable. In this paper we propose a new method for calculating image complexity based on Region Of Interest (ROI) concept. After that we analyze three complexity measures named: Image compositional complexity (ICC), Quad tree and ROI method, with three different watermarking algorithms that are in Spatial, DCT and Wavelet domain to find a relation between complexity and capacity. Our experiments on 200 images show that the proposed ROI measure has the best adoption with watermarking capacity based on a visual quality degradation calculated by MSSIM\(^1\). In addition, we found that there is an interesting arbitrary linear relation between watermarking capacity in bit per pixel with image complexity. This will open a new trend in calculating capacity of images based on their content.

Keywords: Image Watermarking, Capacity, Region Of Interest (ROI), Complexity

1 - Introduction
Determining the capacity of watermark in an image means finding how much information can be hidden in a digital image without perceptible distortion, while maintaining its robustness. This definition indicates that calculating watermarking capacity in images is a complex problem, because it is influenced by many factors. Generally, three parameters in watermarking have the most important role: capacity, quality and robustness. These parameters have opposite effect on each other. For example, improving the robustness will decrease image quality or enhancement in quality will decrease capacity or vice versa.

Some works for calculating watermark capacity are reported. In Moulin works, the concept of information hiding was used to calculate the capacity by considering watermarking as an information channel between transmitter and receiver [1]. Voloshynovisky introduced Noise Visibility Function (NVF) which estimates the allowable invisible distortion in each pixel according to neighbor's values [2]. Zhang in [3] and authors in [4] showed how to use heuristic methods to determine the capacity.

Some approaches pay more attention to attacks model and communication channel than the image content. We can not neglect the fact that image content, represented here by the term, image complexity, has a very important role in capacity. This encouraged us to find the relation between complexity (which is content dependent) and capacity. Generally it is assumed that complex images have more capacity than simple ones but we didn’t find any work that systematically analyses the relation between complexity and watermarking capacity. This relation will help us to understand the images content role in capacity estimation and it provides new aspects in watermarking capacity beyond the limitation of information theory which generally focus on modeling attacks and additive noise effect on capacity.

In this paper we will introduce a new measure that is appropriate for complexity estimation. After that we will show that this method has the best match with quality degradation in fixed size watermarking. The rest of paper is organized as follows. In section 2 we discuss three methods for estimating complexity. In section 3, images are watermarked according to their capacity provided by three complexity measures. Experimental results and conclusions are discussed in sections 4 and 5.

2- Complexity measures
Images, depending on their content, have different complexities. However, a single image may be

\(^1\) Mean Structural Similarity Index Measure
classified in different complexity classes by different viewers. This means that background knowledge will effect on complexity concept. But there is a global agreement in classifying images by complexity. Fig.1 shows nine images with different detail or complexity that we have used for our experiments. In this section we will describe briefly three measures for calculating image complexity.

Fig.1 Nine images with different complexities. In your opinion, how complex are these images?

**2-1 Image Compositional Complexity (ICC)**

This measure is fully described in [5]. Briefly, this measure can be interpreted as the spatial heterogeneity of an image from a given partition. The Jensen-Shannon divergence measure is applied and the segmentation phase has an important role in this method. Thus, given an image partition, we can express the heterogeneity of an image using the JS-divergence applied to the probability distribution of each region.

**2-2 Quad tree method**

We have introduced this measure in our previous work, which is fully described in [6]. Quad-tree representation is introduced for binary images but it can be obtained for gray scale images, too. For a gray scale image, we use the difference between maximum and minimum gray levels at each block and intensity variance in them as a measure of contrast. If these values are lower than a predefined threshold it means that there is not much detail in that block (i.e. there are too much similarity among the pixels of the block), thus, that block is not divided further. Otherwise, the division of that block into 4 blocks is continued until either a block can not be divided any more, or reaching to a block size of one pixel.

Assume $i$ be the level number in quad tree with $n$ levels, and $N_i$ be the number of nodes in level $i$, then we define the complexity as follow:

$$\text{Complexity} = \sum_{i=1}^{n} (N_i \times 2^i)$$

Then the complexity values are normalized in $[0, 1]$.

**2-3 Region OF Interest method**

One of the most interesting subjects in image processing fields is finding regions of image that have more attractiveness for human eyes. This is the subject of Region of Interest (ROI) detection in images [7]. We suggest an idea that if we can rank the image blocks in according to their ROI scores, then we can estimate the image complexity based on the total scores of image blocks. For finding the region of interest value of image blocks, we used the method in [7] with some modifications. Briefly this method divides the image into some blocks and by calculation of five parameters such as intensity, contrast, location, edginess and texture; estimates the block scores in corresponding to theirs ROI attractiveness.

Our modification is in calculation of edginess parameter that we used Canny edge detection method with threshold 0.7. Using this threshold means that minor edges which usually occur in background can not affect on ROI calculation. In addition we decrease the intensity parameter role in estimation of ROI score because our experiments showed that the proposed method in [7] has high sensitivity to white regions.

Finally, for calculating the complexity of an image, we divide the image into 16*16 blocks and calculate each block interest scores based on our modified algorithm. Therefore we have the ranks or scores for sub images. These ranking are shown in Fig 2 for two images, Couple and Lena. (Note that only 8 higher score blocks are shown by numbers 1..8 on upper left corner of blocks)

**Fig 2 – Ranking of sub images based on ROI calculation**

After calculation of ROI score in each sub image, we assumed that the sum of all sub image scores will give a good estimation for image complexity. This means
that images with high contrast, edginess and texture could be considered as image with high complexity. Table 1 shows the result of complexity for 9 standard images of Fig 1, calculated by three above mentioned methods (ICC, Quad tree and ROI). (Complexities are normalized in [0..1]).

3- Watermarking capacity and complexity

In this section we use three famous watermarking algorithms for finding the relation between complexity measures and watermarking artifacts on images. These algorithms are amplitude modulation [8] in spatial domain, Cox method in DCT domain [9] and Kundur algorithm in wavelet domain [10]. For simplicity, we will refer to these algorithms as Spatial, DCT and Wavelet in this paper.

Table 1 Complexity results for images in Fig1

<table>
<thead>
<tr>
<th>Image label</th>
<th>ICC</th>
<th>Quad tree</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>0.76</td>
<td>0.78</td>
<td>0.93</td>
</tr>
<tr>
<td>(b)</td>
<td>0.65</td>
<td>0.45</td>
<td>0.32</td>
</tr>
<tr>
<td>(c)</td>
<td>0.82</td>
<td>0.91</td>
<td>0.90</td>
</tr>
<tr>
<td>(d)</td>
<td>0.59</td>
<td>0.65</td>
<td>0.68</td>
</tr>
<tr>
<td>(e)</td>
<td>0.83</td>
<td>0.83</td>
<td>0.95</td>
</tr>
<tr>
<td>(f)</td>
<td>0.68</td>
<td>0.61</td>
<td>0.57</td>
</tr>
<tr>
<td>(g)</td>
<td>0.48</td>
<td>0.73</td>
<td>0.62</td>
</tr>
<tr>
<td>(h)</td>
<td>0.53</td>
<td>0.57</td>
<td>0.71</td>
</tr>
<tr>
<td>(i)</td>
<td>0.79</td>
<td>0.80</td>
<td>0.89</td>
</tr>
</tbody>
</table>

We selected algorithms in different domains to understand the relation between complexity and watermarking capacity in those domains. We used 200 different images (includes grayscale version of LIVE image database [12]) and calculated the complexity measure of each image using the three measures discussed in section 2. Different resolution helps us to understand the relation between complexity and capacity independent of image size and resolution. Then we watermarked each image using three watermarking methods mentioned before. To compare the visual quality after watermarking we used the MSSIM (state of the art image quality assessment measure) [11]. It seems that this measure consider structural similarity as human visual system does. This provides better results compared with the traditional methods such as PSNR\(^2\) [11].

In our experiment we used a watermark pattern with 256 bits in all three watermarking methods. 256 bits is a usual size for watermark. To compare the results, Figs.3 to 5 shows the relation between each complexity measure and the visual degradation measures (MSSIM). We will discuss about these Figs in section 4 but there is an interesting linear above the relation between image complexity calculated by ROI method and visual quality.

4. Discussions on experimental results

Figures 3 to 5, provide some interesting results that are explained in following.

---

\(^2\) Peak Signal to Noise Ratio
A) In Figs.3 to 5, a simple relation between image complexity and visual quality can be understood. That is, when complexity of an image is higher, then the visual quality of watermarked image is higher too (e.g. higher MSSIM). This shows that, complex images have higher capacity for watermarking.

B) In Fig. 5 a linear relation between capacity and complexity can be determined. This linear relation gives us the opportunity to calculate the watermarking capacity by its complexity. This can be a new trend for calculating watermark capacity.

C) It seems that the ROI measure can give better estimation on capacity because as seen in Fig. 5, the curves have a straight ascending line. But in ICC and Quad tree methods (Figs. 3, 4) there are some irregularities between complexity value and quality measures.

D) Wavelet method shows a better match with quad tree measure. This is because of the linear shape curve of MSSIM in wavelet method as shown in Fig. 4. This is a logical fact, because the complexity measure based on Quad tree uses similar concept of dividing an image into 4 blocks as used in multi-scale watermarking methods such as wavelet.

E) It seems DCT and Wavelet methods create watermarked images with better visual quality in overall. This is because the curve corresponding to spatial method is lower than that of wavelet and DCT. (Figs 3 to 5).

5. Conclusion

In this paper we introduced a new method for calculating image complexity based on region of interest concept. After that we analyzed the relation between different complexity measures with watermarking capacity. We used a fixed watermark size (256 bits), and then calculated the degradation of images with MSSIM quality measure with three different watermarking algorithms in spatial, wavelet and DCT domains. Our analysis showed that our proposed ROI measure has produced better results which are in match with empirical results.

The results of our research showed that in different domains of watermarking the relation between image content (complexity) and its capacity can be determined. In this way if the aim is to have larger capacity of watermark for a given host image, then the appropriate domain can be selected.

In our future work we will try to find a quantitative approach for calculating watermark capacity based on image complexity.

Acknowledgment

This research was financially supported by Iran Telecommunication Research Center (ITRC), as a PhD thesis support program.

References

4. F.Yaghmaee, M.Jamzad “Computing Watermark Capacity in Images according To Their Quad Tree”, IEEE ISSPIT 2005, Athens, Greece