Robust Hash Functions for Visual Data: An Experimental Comparison*

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Abstract

Robust hash functions for visual data need a feature extraction mechanism to rely on. We experimentally compare spatial and transform domain feature extraction techniques and identify the global DCT combined with the cryptographic hash function MD-5 to be suited for visual hashing. This scheme offers robustness against JPEG2000 and JPEG compression and qualitative sensitivity to intentional global and local image alterations.

1 Introduction

The widespread availability of multimedia data in digital form has opened a wide range of possibilities to manipulate visual media. In particular, digital image processing and image manipulation tools offer facilities to intentionally alter image content without leaving perceptual traces. Therefore, it is necessary to provide ways of ensuring integrity other than human vision.
Classical cryptographic tools to check for data integrity like the cryptographic hash functions MD-5 or SHA are designed to be strongly dependent on every single bit of the input data. While this is desirable for a big class of digital data (e.g. executables, compressed data, text), manipulations to visual data that do not affect the visual content are very common and often necessary. This includes lossy compression, image enhancement like filtering, and many more. All these operations do of course change the bits of the data while leaving the image perception unaltered.
To account for this property of visual data new techniques are required which do not assure the integrity of the digital representation of visual data but its visual appearance. In the area of multimedia security two types of approaches have been proposed to satisfy those requirements in recent years: semi-fragile watermarking and robust multimedia hashes (see [1, 2, 4, 3, 5, 6, 7] for some examples for the latter approach).
Main advantages of semi-fragile watermarking schemes are that watermarks are inserted into the image and become integral part of it and that image manipulations may be localized in most schemes. The main advantage of hashing schemes is that image data is not altered and not degraded at all.
In this work we focus onto robust visual hash functions to provide a means to protect visual integrity of image data. In particular, we propose to combine the extraction of robust visual features with the application of a classical cryptographic hash function to result in a robust visual hash procedure. In section 2 we first discuss requirements of a robust visual hashing scheme. Subsequently, we introduce several possibilities to extract perceptually relevant visual features in the spatial and transform domain. In section 3, we experimentally evaluate robustness against JPEG 2000 and JPEG compression and sensitivity towards intentional modification of visual hashing schemes based on the feature extraction techniques proposed in section 2 and the cryptographic hash function MD-5. Section 4 concludes our paper and provides an outlook to future work in this direction.

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2 Approaches to Robust Visual Hashing

Similar to cryptographic hash functions, robust hash functions for image authentication should satisfy 4 major requirements [7] (where P denotes probability, H is the hash function, $X, \hat{X}, Y$ are images, α and β are hash values, and $\{0/1\}^L$ represents binary strings of length L):

1. Equal distribution of hash values:
$$P[H(X) = \alpha] \approx \frac{1}{2^L}, \forall \alpha \in \{0/1\}^L .$$
2. Pairwise independence for visually different images X and Y:
$$P[H(X) = \alpha | H(Y) = \beta] \approx P[H(X) = \alpha] ,$$
$$\forall \alpha, \beta \in \{0/1\}^L .$$
3. Invariance for visually similar images X and $\hat{X}$:
$$P[H(X) = H(\hat{X})] \approx 1 .$$
To fulfil this requirement, most proposed algorithms try to extract image features which are invariant to slight global modifications like compression or filtering.
4. Distinction of visually different images X and Y:
$$P[H(X) = H(Y)] \approx 0 .$$
This final requirement also means that given an image X, it is almost impossible to find a visually different image Y with $H(X) = H(Y)$. In other words, it should be impossible to create a forgery which results in the same hash value as the original image. Note that the visual features selected according to requirement 3) are usually publicly known and can therefore be modified. This might threaten security, as the hash value could be adjusted maliciously to match that of another image.

Note that requirements 1), 2), and 4) also apply to cryptographic hash functions, whereas requirement 3) focuses entirely onto the desired robustness property.
Our approach investigated in this work therefore basically consists of two steps:

- First, features robust to common (non-hostile) image processing operations (we especially focus onto compression) but sensitive to malicious modifications are extracted from the image.
- Subsequently, a classical hash function is applied to those features (MD-5 in our case).

3 Feature Extraction techniques

3.1 Multiresolution pyramids

As a first step we construct a quater-sized version of the image ("approximation") using a 4-pixel average (AV) or a 4-pixel median (ME). Subsequently, the construction of the approximation is iterated to construct smaller versions. An approximation of specific size is used as feature. Whereas the bitdepth is not influenced by these operations (AV is rounded to integer) we only obtain a limited number of differently sized approximations the hash function may be applied to: 256^2 values for one iteration, 128^2 values after two iterations, ..., and $16^2 = 256$ values after five iterations which is the maximal number of iterations we consider.

3.2 Bitplanes

We consider the 8bpp data in the form of 8 bitplanes, each bitplane associated with a position in the binary representation of the pixels. The feature extraction approach is to consider a subset of the bitplanes only, starting with the bitplane containing the MSB of the pixels. Each possible subset of bitplanes may be chosen as feature, however, it makes sense to stick to the order predefined by the significance of the binary representation. After having chosen a particular subset of bitplanes, the hash function is applied to pixel values which have been computed using the target bitplanes only. Note that the smallest amount of data the hashing may be applied to (i.e. one bitplane) corresponds to 32768 pixels in this case (1/8 of the total number of pixels in the image). Note also that this feature extraction technique BP comes for free from a computational point of view.

3.3 DCT

The DCT is well known to extract global image characteristics efficiently and is used for watermarking applications for these reasons (see e.g. Cox's scheme). We use the DCT in two flavours: as full frame DCT (DCT1) and as DCT applied to 8×8 pixels blocks (DCT2) due to complexity reasons. Following the zig-zag scan order (compare e.g. JPEG) we apply the hash-function to a certain number of coefficients or a certain number of coefficients from each block, respectively. Given a 512×512 pixels image and using DCT2, the lowest number of coefficients the hash function may be applied to is 4096 (i.e. the DC coefficient is hashed only for each block), whereas the number of coefficients subjected to hashing may be set almost arbitrarily with DCT1.

3.4 Wavelet Transform

In many applications wavelet transforms (WT) compete with and even replace the DCT due to their improved localization properties (e.g., the WT is used in many watermarking schemes). We use the Haar transform due to complexity and sensitivity reasons. Equivalently to the Multiresolution pyramids, the decomposition depth is a parameter for this method, in case of WT the hash function is applied to the approximation subband only. As it is the case for Multiresolution pyramids, we only obtain a limited number of differently sized approximation subbands the hash function may be applied to. Note that the data subjected to hashing resulting from applying the WT is equivalent in principle to that obtained by the Multiresolution pyramid AV.

4 Experiments

The aim of the experimental section is to investigate whether the introduced visual hashing schemes are

- indeed robust to JPEG and JPEG2000 compression and
- sensitive to intentional image modifications (i.e. attacks).

4.1 Experimental Settings

We use the classical 8bpp, 512×512 pixels Lena image as testimage. In order to investigate the robustness of the visual hashing schemes, we subject the image to JPEG 2000 (J2K) and JPEG compression with different compression ratios (Cr). The sensitivity to intentional and/or malicious image modifications is assessed by conducting local and global image alterations:

- Adding a small artificial birthmark to Lenas upper lip ("augmented Lena") - local
- Applying Stirmark attack option b - global

4.2 Results

The tables display the minimal number of feature values required to detect image modifications. Below you find the values for the multiresolution pyramids AV and ME. Note that the smallest number considered is $16^2 = 256$ which corresponds to 5 iterations of constructing approximations to the image. A larger entry in the table corresponds to higher robustness against the type of attack (desired or not) as indicated in the leftmost column. In this table we consider only the three most significant bitplanes.

	AV			**ME**		
Attack	3 BP	2 BP	MSB	3 BP	2 BP	MSB
J2K Cr 2	16^2	32^2	64^2	16^2	16^2	64^2
J2K Cr 14	16^2	16^2	32^2	16^2	16^2	16^2
JPEG Cr 1.7	64^2	64^2	64^2	16^2	32^2	32^2
JPEG Cr 7.6	32^2	32^2	32^2	16^2	16^2	16^2
Stirmark	16^2	16^2	16^2	16^2	16^2	16^2

We notice robustness to a certain extent against JPEG 2000 and JPEG compression. For example, J2K compression is not detected using 16^2 features up to Cr 14 using the MSB only when employing AV. JPEG compression is not even detected using 32^2 features up to Cr 7.6 even when employing three bitplanes and AV.
Concerning malicious modifications, sensitivity against Stirmark attacks is high as being desired. For example, choosing AV as multiresolution pyramid and selecting the MSB of 16^2 feature values (i.e. 5 decompositions) is robust against all compression settings considered and reveals all global attacks discussed. The situation changes when we investigate the sensitivity against local attacks – we notice extremely low sensitivity with respect to the Lena with birthmark image.
When turning to bitplanes as a means to feature extraction it turns out immediately that there is no way to make such a scheme robust to compression at all.
Now we turn to the transform domain. In the table below we display the results concerning the full frame DCT (DCT1). In contrast to the multiresolution pyramids, the number of feature values may be varied continously.
Even when using full 8bpp precision for the feature values we still require 40 values to detect a J2K compression with Cr 14, the same is true for JPEG compression with Cr 13. Consequently we may state that robustness against compression may be achieved.

Attack	Full	7 BP	5 BP	4 BP	2 BP	MSB
J2K Cr 2	40	40	54	>200	>200	>200
J2K Cr 10	40	40	40	162	>200	>200
J2K Cr 14	40	40	40	79	174	>200
JPEG Cr 1.7	55	65	>200	>200	>200	>200
JPEG Cr 6.1	54	54	65	65	>200	>200
JPEG Cr 13	40	40	65	65	174	175
Birthmark	40	40	43	43	**72**	175
Stirmark	4	4	4	4	4	4

Sensitivity against intentional attacks, on the other hand, is satisfactory for all types of attacks. For those attacks sensitivity is always higher as against the strongest compression considered. As a consequence, we may define DCT1 based visual hash functions which are sensitive to all attacks considered but robust to moderate compression. As a concrete example, we could use 2 bitplanes of 80 feature values. In this case the number of feature values to detect J2K and JPEG compression is significantly higher (174 in either case of maximal compression) and therefore this hash function is also robust against even more severe compression. On the other hand, all considered attacks are revealed including the Lena with bithmark which is detected using 72 feature values (displayed boldface in the table).
Wavelet transform, being equivalent to the multiresolution pyramid AV due to the use of Haar filters, is not further discussed.

5 Conclusion

We have found that global DCT seems to be the most suitable feature extraction approach to base a robust visual hash function upon if robustness against moderate compression is a prerequisite for such a scheme. Although the computationally most demanding approach, the robustness against JPEG2000 and JPEG compression and the responsiveness to intentional global and local image alterations exhibited by the DCT based system are by far superior as compared to the competing wavelet transform and multiresolution pyramid based schemes. Visual hash functions based on block-based DCT and selective bitplane hashing have failed to provide robustness against compression.
In future work we will **add** to the qualititive approach based on the cryptographic hash function MD-5 ("tampered with or not") a quantitative one tailored to the DCT domain allowing to additionally rate the amount of image alteration in case of detected tampering and we will evaluate the security of the scheme.