DIGITAL IMAGE FORENSICS FOR IDENTIFYING COMPUTER GENERATED AND DIGITAL CAMERA IMAGES

Sintayehu Dehnie, (Taha Sencar, Nasir Memon)*†

Polytechnic University
5 MetroTech Center
Brooklyn, NY 11201

ABSTRACT

We describe a digital image forensics technique to distinguish images captured by a digital camera from computer generated images. Our approach is based on the fact that image acquisition in a digital camera is fundamentally different from the generative algorithms deployed by computer generated imagery. This difference is captured in terms of the properties of the residual image (*pattern noise* in case of digital camera images) extracted by a wavelet based denoising filter. In [1], it is established that each digital camera has a unique pattern noise associated with itself. In addition, our results indicate that the two type of residuals obtained from different digital camera images and computer generated images exhibit some common characteristics that is not present in the other type of images. This can be attributed to fundamental differences in the image generation processes that yield the two types of images. Our results are based on images generated by the Maya and 3D Studio Max software, and various digital camera images.

Index Terms: Computer graphics, image analysis, image classification, image processing, .

1. INTRODUCTION

Advances in digital imaging technologies raised new issues and challenges concerning the integrity and authenticity of digital images. Digital images can now be easily created, edited and manipulated without leaving any obvious traces of such operations. These capabilities undermine the credibility of digital images in all aspects. Digital image forensics is an emerging research field aiming at determining the origin and potential authenticity of a digital image.

One of the fundamental problems digital image forensics techniques attempt to solve is the identification of the source of a digital image. That is, to determine by what means a digital image has been created, e.g., digital camera, scanner, generative algorithms, etc. Possible solutions to the problem of image source identification may include one of the below approaches:

1. Verifying and evaluating the image statistics that are inherent to real-life sceneries and objects.
2. Detecting, classifying and measuring the qualities of spatial structures (i.e., color, texture and edge structures) in an image.
3. Identifying signatures to detect traces of certain types of operations used in image generation process by possible sources.

*Electrical and Computer Engineering Department
†Computer and Information Science Department

In this work, we study a specific instance of this problem which involves identifying whether a given image is a depiction of a real-life occurrence (and objects) or a fictitious realization. That is, distinguishing digital images generated by a digital camera from the ones generated by a computer graphics renderer. Our approach is motivated by the hypothesis that image acquisition in a digital camera includes many common processing stages (regardless of the specific digital camera used in capturing the image) leaving a unique signature in certain properties of the resulting image which may not necessarily be present in synthetically generated images. This is because the methodology governing the generative algorithms is fundamentally different from the image acquisition pipeline in a digital camera. Although this approach by itself cannot fully address the source identification problem (as it cannot resolve cases where a digital camera is used to capture the image of computer generated scene and objects), it is an important component of image forensics techniques.

In [1], Lukas et al. argued that images from a given digital camera exhibit a unique stochastic characteristic due to the pattern noise introduced in the medium to high frequency content of an image during image acquisition. Furthermore, they showed that the presence of the pattern noise can be detected by correlative processing, and an image can be uniquely associated with a digital camera through the known *reference error pattern*. In their work, the *reference error pattern* of a specific digital camera is the averaged noise pattern, obtained through image denoising, from a number of images captured by that camera. *In this paper, we exploit the fact that, although each individual camera has a unique noise pattern associated with it, pattern noise introduced by different digital cameras may have common (statistical) properties, as the deployed image sensor technology remains same, and that this common characteristic will not be present in computer generated images. Similarly, computer generated imagery may exhibit certain common properties, due to the use of same generative algorithms, that are not shared by the digital camera images.* Based on this argument, we investigate the potential of distinguishing computer generated images from digital camera images.

2. METHODOLOGY

As discussed in [1], for a given digital camera, the pattern noise remains approximately unchanged (regardless of the captured illumination from the scene) in each image, and it can be modeled as an additive noise. Furthermore, it is known that the pattern noise is relatively stable over the camera life span and a reasonable range of conditions such as temperature. Because of these properties we assume that traces of pattern noise is a reliable indicator that can be used to distinguish digital camera images from computer generated images.

To test the validity of the assumption that digital camera and computer generated images are the result of two fundamentally different set of operations and that common properties of pattern noise associated with each type of images is not shared by the other type, we take an approach similar to that of [1]. For this purpose, we generate a reference noise pattern for a class of computer generated images using a given algorithm. We obtain the reference pattern by applying a wavelet based denoising filter [2] to extract the noise from each image. The denoising filter is derived from a bivariate statistical model that takes into account the statistical dependency between adjacent wavelet coefficients of natural images. This form of denoising filter is one of the best filters available for image denoising in the literature. Figure 1 shows the system block diagram. The denoising filter is locally adaptive[3] and includes a robust median estimator [4] in order to estimate the noise variance. Let X denote an image and $\hat{X}$ denote its denoised version. The pattern noise, e, is given by

$$e = X - \hat{X} \quad (1)$$

The reference noise pattern, e_{ref}, is obtained by averaging over

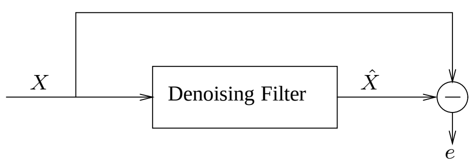


Fig. 1. System Model.

many instances of e.

The identification of image type is established by correlating the image residual with the pre-computed reference error pattern associated with a generative algorithm. To classify a given image X as digital camera or computer generated image, the normalized correlation between the residual image, e (1), and the reference error pattern of a generative algorithm is computed as

$$\rho = \frac{(e - E[e])(E_{ref} - E[E_{ref}])}{||e - E[e]||||E_{ref} - E[E_{ref}||} \quad (2)$$

where $E[\ ]$ is the expected value.

3. RESULTS

In our experiments we consider two sets of computer generated digital images. The first set is generated using Maya software, whereas the other set is generated using 3D Studio Max software. The images were obtained from publicly available websites [5] where it is explicitly noted that the images were generated by Maya and 3D Studio Max software, and other software suites, like Photoshop, for texture design purposes. The digital camera images are also obtained form publicly available websites [6] and divided into three sets. The first two sets are from a personal folder and involve images taken by two different cameras. The first set of images are taken by the (same) FUJI FinePixS2 Pro Digital Camera, whereas the second set of images are taken by the Kodak DCS Pro SLR/n Digital Camera. The third set involves images (each) taken by different digital cameras (from different folders) including various digital camera makes and models. In all cases, some of the images are used for obtaining the reference error pattern and the rest is used for test and evaluation of the method.

To establish the presence of a statistical difference between computer generated and digital camera images, we measured the statistics of each residual image for four different pairs of image sets. Each pair contains two sets of 100 Maya and digital camera images. The results are shown in Figure 2 and 3. We observed that the mean value of extracted noise from camera images is relatively higher. It is also observed that noise extracted from Maya images exhibit a relatively lower skewness (higher kurtosis).

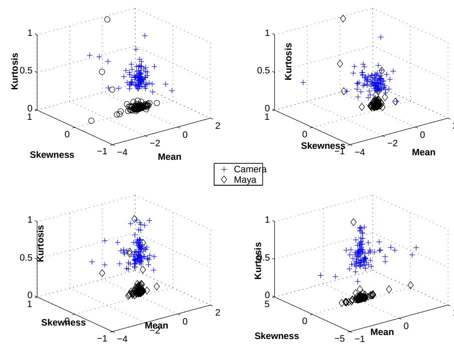


Fig. 2. Measured statistics of residual image for different sets of images.

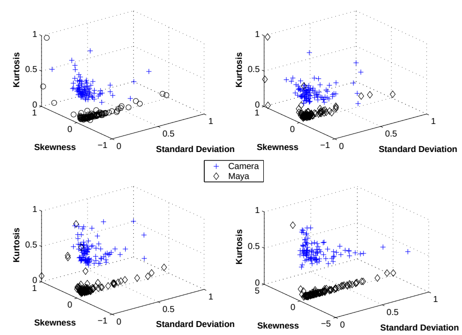


Fig. 3. Measured statistics of residual image for different sets of images.

We showed above the statistical variations in camera and Maya images. This statistical variation should be preserved in the reference error pattern generated from multiple images. In the next experiment we computed correlation of the reference error pattern with error extracted from test images. In our experiments, correlation of image residual with reference patterns is considered for three different cases. In the first case, the reference pattern is generated considering all subbands (HL, LH, and HH) in the wavelet transform domain. In the second case, the reference error pattern is generated by excluding the HL subband. In the last case, only the HH subband is considered when the reference error pattern is generated. In this paper we show results from the experiment that involves all the high-frequency wavelet coefficients. Figures 3 shows the correlation of the test images with the reference error pattern each obtained from the 300 images taken by different cameras. The figures depict that the test camera images exhibit stronger correlation with the reference error pattern. On the other hand, we observed that Maya and 3D

Studio Max test images have weaker but non-zero correlation to the reference error pattern. The statistics (histogram) for the computed correlation coefficient are as shown in Figure 4. The mean values for the computed correlation are (0.0319, 0.0395) for Maya and 3D Studio Max test images respectively. On the other hand, the mean of the correlation of the camera test image is 0.1228. This further validates the argument that digital cameras have common stochastic features that may not be present in computer generated images. To measure

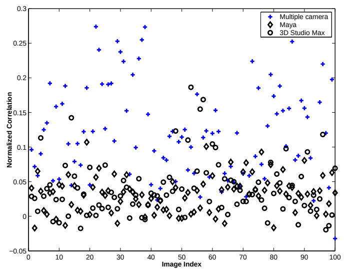
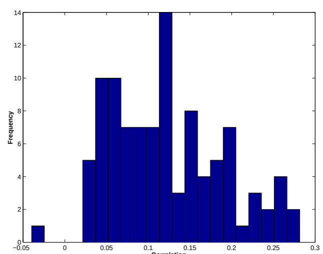
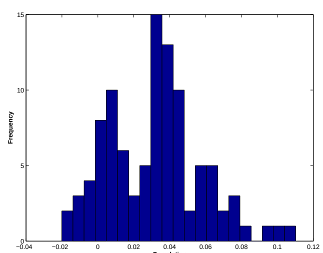


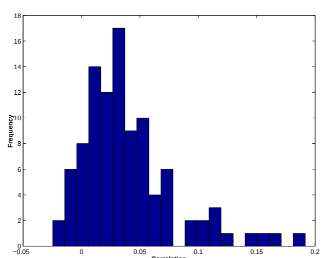
Fig. 4. Correlation of test image residual with reference error pattern obtained from different cameras.



(a) Histogram of correlation of camera test image.



(b) Histogram of correlation of Maya test image.



(c) Histogram of correlation of 3D Studio Max test image.

Fig. 5. Correlation statistics of test image residual with multi-camera reference error pattern.

the false positive rate of the above experiment, ROC curves were generated and are shown in Figure 5. We repeated the experiment

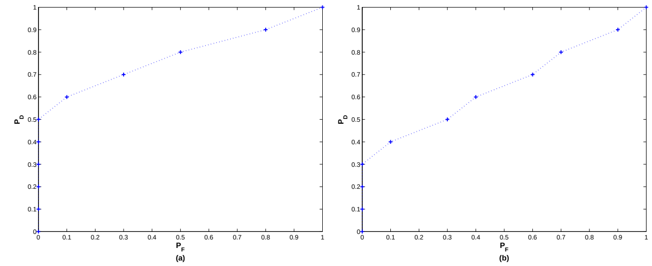


Fig. 6. ROC curves to measure false positive rate, (a) Maya, (b) 3D Studio Max.

using reference error patterns obtained from the 300 images taken by FUJIFinePix S2 Pro and Kodak DCS Pro SLR/n respectively. Figures 6 and 7 show the corresponding correlation for each reference error pattern with the test images. Parallel to the results in [1], we observed that test images (from the same camera) showed stronger correlation with the reference error pattern. Similar to the previous experiment, Maya and 3D Studio Max images exhibit weaker but non-zero correlation. We did a similar experiment by obtaining a

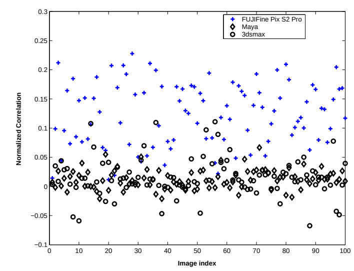


Fig. 7. Correlation of test image residual with camera reference error pattern.

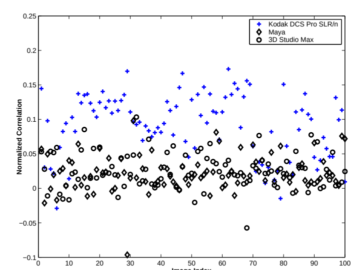


Fig. 8. Correlation of test image residual with camera reference error pattern.

Maya reference error pattern (e_{maya}) using 300 images. The results are shown in Figure 8. Similar to the previous two cases, a stronger correlation of the Maya reference error pattern with the test Maya images is observed. In agreement with our argument, the correlation of the camera test images with the Maya reference pattern exhibit weaker but non-zero correlation. This is an indication that Maya images also have a unique stochastic feature. The correlation statistics is as shown in Figure 9. We also measure the false positive rate of the above experiment by generating ROC curves as is shown in Figure 10. We repeated the experiment using Maya reference error

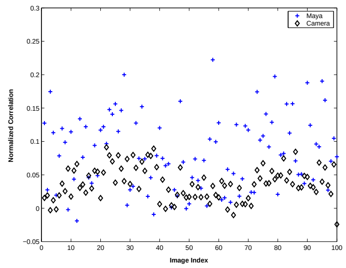


Fig. 9. Correlation of test image (different cameras) residual with Maya reference error pattern.

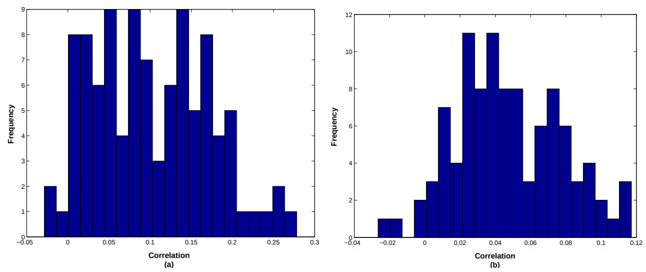


Fig. 10. Statistics of (histogram) correlation with Maya reference error pattern, (a) Maya, (b) Cameras

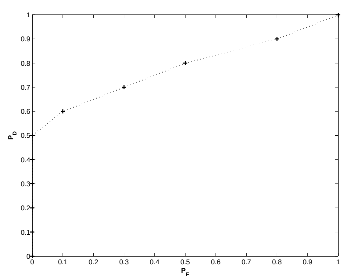


Fig. 11. ROC curve to measure false positive rate.

pattern and two sets of test camera obtained from two different cameras. The results are shown in Figure 10. Ultimately, to verify that

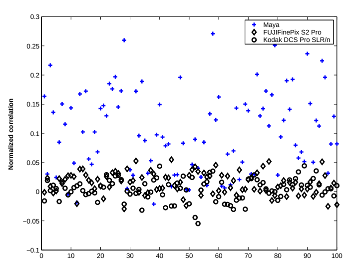


Fig. 12. Correlation of test images with Maya reference pattern.

properties of Maya reference pattern is not image set dependent, we generated two (non-intersecting) sets of 150 Maya images. We obtained the reference error pattern and computed the correlation with the test Maya images. Figure 12 depicts the measured correlation. These values establish consistency for Maya reference error pattern in capturing the common properties of the residual error in Maya images.

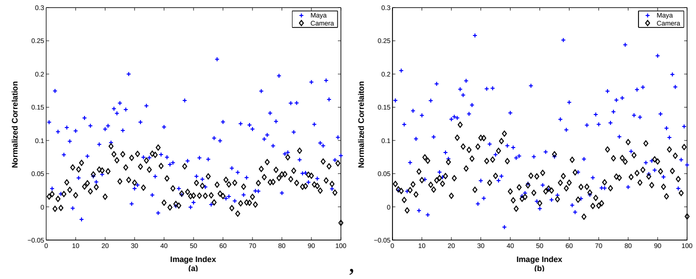


Fig. 13. Correlation of test image correlation with two (different) Maya reference error pattern, (a) Set I, (b) Set II.

4. CONCLUSION

In this paper, we argued that digital camera images exhibit a common statistical property which is not present in computer generated images and vice versa. Based on this argument, we proposed a method to differentiate between digital camera images from computer generated images.

We observed that test Maya images exhibit higher correlation with the Maya reference error pattern. The higher correlation in Maya images indicates the presence of unique statistical properties in Maya images.On the other hand, we observed low correlation with the Maya reference error pattern when test images from a given camera and multiple camera are used. We also showed consistency in Maya reference error pattern using two sets of Maya images. Mixed test images exhibit relatively higher correlation with the considered digital camera reference error pattern compared to Maya test images. This further validates the argument that digital camera images exhibit common statistical properties.

5. REFERENCES

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