SOURCE CAMERA IDENTIFICATION BASED ON SENSOR DUST CHARACTERISTICS

A. Emir Dirik

Polytechnic University
Department of Electrical
and Computer Engineering
Brooklyn, NY, US

Husrev T. Sencar, Nasir Memon[*]

Polytechnic University
Department of Computer
and Information Science
Brooklyn, NY, US

ABSTRACT

A problem associated with digital single lens (DSLR) cameras is *sensor dust*. This problem arises due to dust particles attracted to the sensor, when the interchangeable lens is removed, creating a dust pattern in front of the imaging sensor. Sensor dust patterns reveals themselves as artifacts on the captured images and they become more visible at smaller aperture values. Since this pattern is not changed unless the sensor surface is cleaned, it can be used to match a given image to source DSLR camera. In this paper, we propose a new source camera identification method based on sensor dust characteristics. Dust specks on the image are detected using intensity variations and shape features to form the dust pattern of the DSLR camera. Experimental results show that the method can be used to identify the source camera of an image at very low false positive rates.

1. INTRODUCTION

In today's digital age, the creation and manipulation of digital images is made simple by digital processing tools that are easily and widely available. As a consequence, we can no longer take the authenticity of digital images for granted. Today, there is a severe lack of techniques and methodologies for verifying the integrity of digital images. Due to this asymmetry, digital images appear to be the source of a new set of problems. This is especially true when it comes to legal photographic evidence. Image forensics, in this context, is concerned with uncovering some underlying fact about an image. To address these problems, more recently, several digital image forensics techniques have been proposed for both image forgery detection [1, 2, 3, 4, 5] and image source identification [6, 7, 8, 9, 10, 11, 12].

In image source identification problem, one of the most pressing concerns is the ability to match an image to its source camera. In this context, the most promising approach is proposed by Lukáš, et. al. [12]. In their method, sensor's pattern noise is used to identify the source of an image. Sensor pattern noise is caused by various factors, such as dust specks on optics, interference in optical elements, dark currents, etc. However, the high frequency component of the pattern noise can be modeled as additive noise and estimated by applying a wavelet based denoising to the captured image. Then, the extracted noise residues from multiple images are averaged to estimate the camera's noise pattern, i.e., reference pattern. To identify the source of a given image, the noise residue of the image in question is correlated with the reference noise patterns extracted from the camera.

In this paper, a new method based on sensor dust characteristics of DSLR cameras for image source identification is proposed. Essentially, the lenses on DSLR cameras are interchangeable and the sensor dust problem arises when the interchangeable lens is removed, thereby opening the sensor area to the hazards of dust and moisture. Once the lens is taken off, the dust particles around the camera are attracted to the imaging sensor by electrostatic fields resulting a dust pattern on the surface of the sensor. (It should be noted that, the dust isn't actually sitting on the sensor itself, but on the element just in front of it. These elements include the dichroic mirror or low-pass filter.) This dust pattern can be seen as small specks, in the form of localized intensity degradations, all over the image under some certain conditions, especially with small aperture settings. In figure 1 a sample image[1] taken with DSLR camera with dust specks are shown. Although it is very hard to locate dust positions, when blockwise local histogram equalization is applied to each pixel in the image, sensor dust artifacts can be easily seen.

Another aspect of the problem is that sensor dust is cumulative. That is, with every change of the lens, more dust is likely to be added to sensor, thereby worsening the problem over the time. Furthermore, most state-of-the-art digital cameras do not offer a built-in solution for removal of sensor dust. On the other hand, the process of sensor cleaning, through swabbing, brushing, using compressed air, brings with it the risk of scratching the sensor. Therefore, sensor dust is a persistent problem that appears to be getting widespread with the

[*]This work is supported by National Institute of Justice grant 2006-92251-NY-IJ.

[1]image is downloaded from www.pbase.com

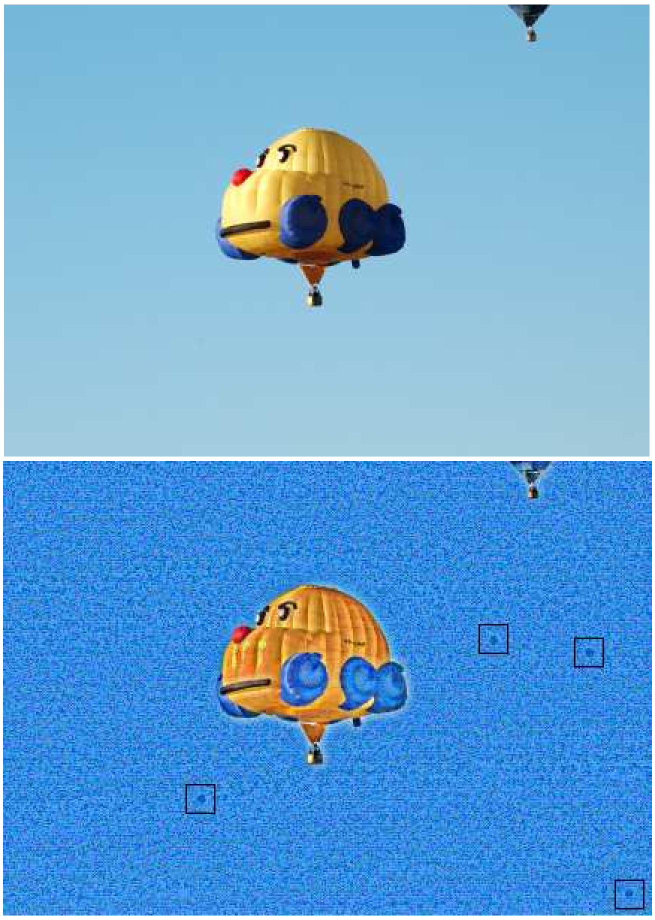

Fig. 1. Sample image taken by NikonD70, f-number:F/14 (up), local histogram equalization result (down). The black boxes show the location of dust specks in the image

advent of DSLR cameras due to superior image quality they provide. It should be noted that since sensor dust problem is not intrinsic to cheaper consumer cameras, the detection of any sensor dust in a given image can be evaluated as a proof of the image source being a DSLR camera. Moreover, with the knowledge of dust positions/pattern in a given image and camera, it is possible to associate images with a particular DSLR camera.

In the following sections a method to locate dust specks in a given image is described. This is primarily achieved by comparing the dust positions of a given image with those of the particular DSLR sensor dust pattern. The efficacy of the proposed method is substantiated by experimental results.

2. SENSOR DUST CHARACTERISTICS AND THEIR FORENSIC USE

Sensor dusts reveal themselves in photos taken with smaller apertures settings and they become less noticeable with increasing aperture values. This is due to the fact that dust spots stand a distance from the actual sensor and wide aperture values let more light to go around the dust spots. Hence the shadow of the dust (speck) on the color sensor shows up in the image as a blurry, soft speck. On the contrary, at small aperture values, the light source can be assumed to be a small pinpoint spotlight as a result of which specks become dark and hard edged [13, 14]. In Fig. 2, the dust spots for two different aperture settings, f/22 and f/32, are shown. It can be seen that the change in f-number affects the intensity and radius of the dust speck and with the increase in f-number (aperture gets smaller) the dust speck gets more darker and smaller.

Fig. 2. Dust specks with different apertures, f/22(left), f/32(right)

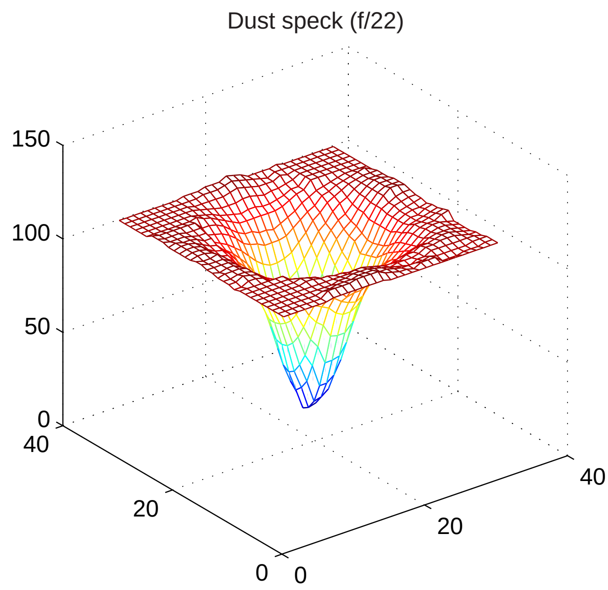

Fig. 3. Intensity loss due to dust speck (f/22)

To exploit this vulnerability of DSLR cameras, we detect traces of sensor dust in images and use it for source identification. For this purpose, we initially aim at determining the presence of dust specks on an image. Due to difficulty in discriminating effects of dust on images from the image content, specifically in the textured and parts with high frequency content, the core element of the method is the dust detection. In other words, the crux of the method lies in dust modeling which essentially determines the rate of false-positives–a crucial parameter concerning its forensic use.

Although some DSLR cameras have anti-dust mechanisms, they can not keep the sensor surface clean completely. Some camera manufacturers also provide post-processing tools to remove dust specks on images based on dust template photos taken with high aperture settings. In the market there are also a couple of commercial softwares which detect and remove dust traces from a single image. Nevertheless all these tools have high false positives. There are also several patents for dust speck detection and removal [14, 15, 16]. In [14] local intensity variations in uniform regions are assumed as dust spots. In [15], likely dust specks are detected by taking the second order derivative of the image and the peaks of the derivatives are assigned as dust positions. In [16] dust positions are detected by taking first-order-derivative and applying some post-processing operations. However, our initial experimental studies showed that gradient based dust spec detection methods suffer from relatively high error rates (miss and false positive probabilities). Therefore, in this work, we did not consider to use any gradient based search method to locate dust positions. Our sensor dust detection method is described below.

2.1. Dust model

Our sensor dust model relies on the observation that sensor dust has two major characteristics: (a) causing an abrupt change on the intensity surface (e.g., intensity loss) depending on the aperture size; and (b) appearing most generally the form of rounded shapes, see figures 2 and 3. To model the intensity degradation due to sensor dust we utilize a 2D inverse gaussian function with a particular standard deviation and gain. It should be noted that as f-number increases the diameter of the dust spot in the image decreases and the intensity loss in the dust spot increases. Moreover, the shape of the intensity loss becomes more kurtotic. Since the dimensions of the dust is related with aperture, its is also essential to detect f-number to locate dust specks properly. (In our work we assume the EXIF data of the image is not available.)

To locate the position of the dust speck, we apply fast normalized cross-correlation [17] with estimated dust model as in equation 1.

$$dustmodel(x, y) = -G\frac{1}{\sqrt{2\pi\sigma^2}} \cdot e^{-\frac{x^2+y^2}{2\sigma^2}} \tag{1}$$

In the equation G refers to the intensity loss. The diameter of the dust speck is controlled by σ. We estimate the diameter

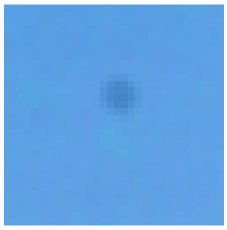

Fig. 4. Dust speck

of dust specks based on cross-correlation results obtained under different σ values ranging from 1 to 3. The sigma value which produces the maximum cross-correlation is chosen as the dust model parameter, and the corresponding correlation output is used to detect dust specks. Once the correlation output is computed, the local maximums higher than a empirically determined threshold (such as 0.4) are labeled as dust candidates. In order to eliminate false positives, dust candidates in highly detailed regions are ignored.

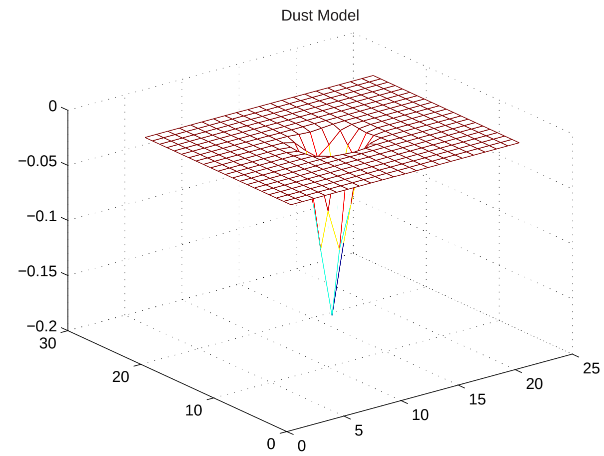

Fig. 5. Dust model, G=1.0, $\sigma = 1.0$

2.2. Contour analysis

Although cross-correlation method works well in smooth regions, it may produce high correlations on edges and textured regions. In order to reduce this sort of false positives, we apply further analysis on each dust candidate based on their local contour characteristics. For each dust candidate we compute their contour map as shown in Fig. 7. Apart from the correlation output, we locate the dust center by analyzing the local minimums which have maximum number of closed loops around. Then, the intensity loss in the possible dust speck region and the eccentricity of the dust contour, which indicates how contour shape resembles to a circle, are computed. These parameters then combined together to compute a normalized

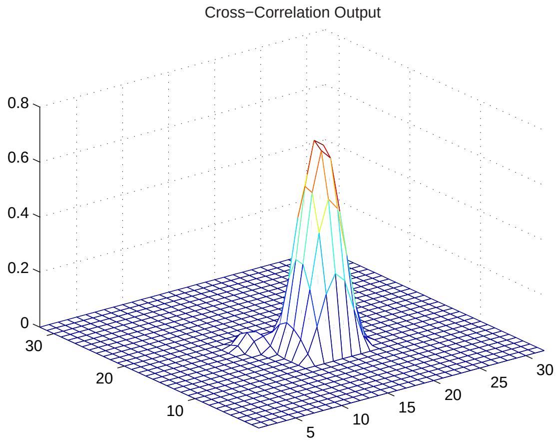

Fig. 6. Cross-correlation output of dust speck in fig. 4

confidence value of the contour region. If there is not any significant intensity loss inside of the contour plot then the confidence value is assigned to zero. After contour analysis, according to the confidence values, each candidate is evaluated to determine the dust specs.

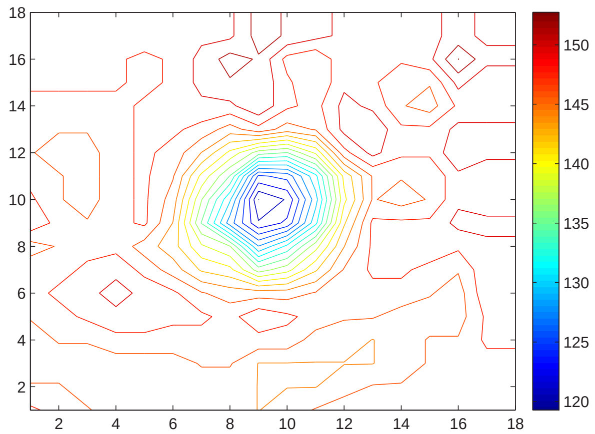

Fig. 7. Contour analysis of dust speck in fig. 4 (Num. of closed loops inside of the speck : 16, intensity loss : 24.3)

2.3. Camera Dust Pattern Generation

To be able to address a forensic setting we assumed two relevant scenarios of dust pattern generation.

- Digital camera is available: In this case the dust pattern of an image can be generated by taking the picture of distant smoothly varying scenery by manually setting the focal length to high values (f/32 or f/36). Then proposed dust detection method is applied to create dust pattern of the camera.
- Images acquired with the DSLR camera are available: When the camera is not available but rather a number of images taken by the camera is present, the dust points that are determined by correlation and through shape characteristics in each image is superimposed together to form the dust pattern/template of the camera. Once the template is created, a threshold is applied to the template to reduce the number of falsely labeled specks in the dust pattern. The underlying idea of applying a threshold to the template is that the actual dust specks should show up at least in two or more images. Since the probability of getting a false dust candidate at the same position in multiple images is very low, we expect that false positives due to image content will be eliminated after thresholding. The dust candidates which have higher confidence values than a fixed threshold are considered to represent the dust pattern of the camera.

Finally, source camera identification model is realized by matching camera dust template with the estimated dust pattern of a given image

3. EXPERIMENTAL RESULTS

Our experiments are based on the assumption that the digital camera is not available and that the sensor dust pattern has to be obtained from a number of images taken by a DSLR camera where obtaining a precise dust template is not easy. To create an image set we have downloaded DSLR images from three different personal galleries at `www.pbase.com`. All images are taken with Sigma SD10. We also created an alternative image data set taken from compact consumer cameras. In order to reduce computation time of cross-correlation, all images are resized to 800x533 pixels. Since dust spots are almost invisible at large aperture rates, images with low f-numbers (below than 8) are not used at experiments.

From each three gallery, we randomly select 10 images to create a dust template. As described in Section 2, we computed the cross-correlation outputs for each image and then superimposed all the outputs to create a camera dust pattern. The contour analysis is then used to refine the final result. After dust patterns of three cameras are computed, in the testing and verification step previously unseen images in each image gallery are analyzed to determine if they include any traces of dust patterns in the locations pointed in the dust template of the camera.

In Figures 8,9,10 we provide results, when the dust template is generated only from 10 images, and tested on 20 images taken by the same and 60 random images taken by other cameras. Our matching results indicate that, we achieve a detection rate around 92% with 0% false positive rate by setting the confidence threshold 1.2. In the figures x-axes shows the image index and y-axes is the proposed metric indicating confidence in the match.

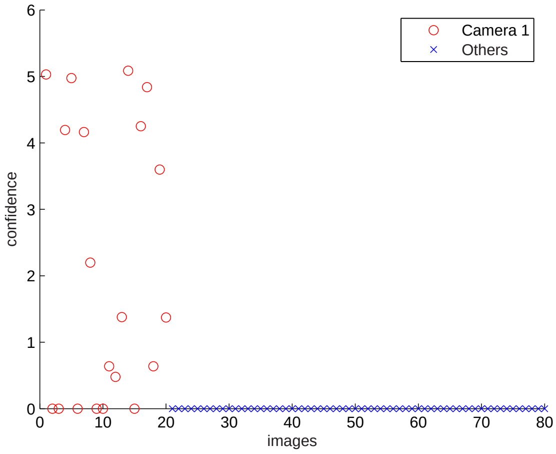

Fig. 8. Num. of matches between the template of the camera 1 and dust candidates. (num. of dusts in the template : 15)

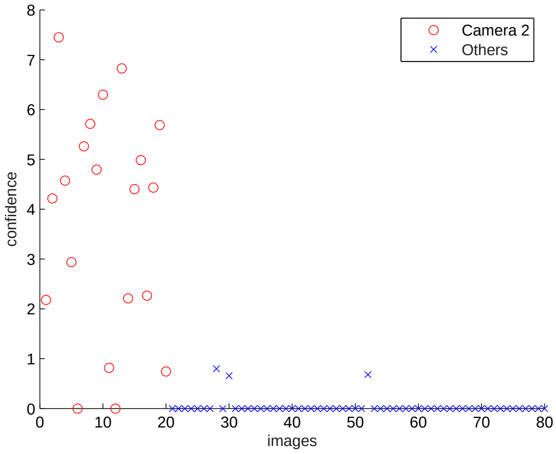

Fig. 9. Num. of matches between the template of the camera 2 and dust candidates. (num. of dusts in the template : 16)

4. DISCUSSION

In this work, we present a source camera identification model for images taken from DSLR cameras. We show that it is possible to associate a given image with a particular DSLR camera with very low false alarm rates using sensor dust characteristics. Though we tested our model with a small set of DSLR cameras, our experimental results are promising. However, there are some problems inherent to the proposed approach. The most important one is that for wide apertures dust specks become almost invisible and detection of the dust

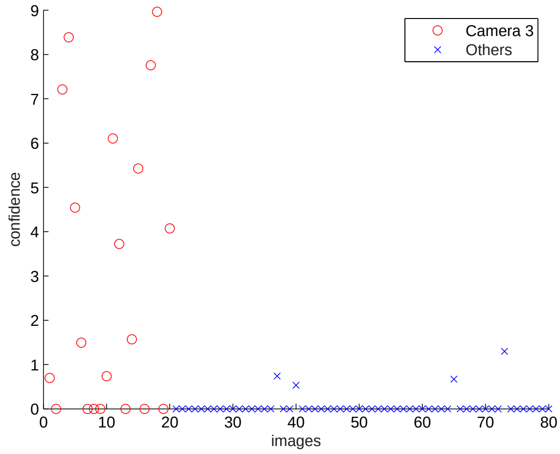

Fig. 10. Num. of matches between the template of the camera 3 and dust candidates. (num. of dusts in the template : 38)

speck becomes a challenging task. Another important problem is the detection of dust specks in non-smooth, complex regions without yielding many false-positives. In the future work, we will address these issues.

5. REFERENCES

[1] A. Swaminathan, M. Wu, and K. J. Ray Liu, "Image tampering identification using blind deconvolution," in *Proceedings of the IEEE International Conference on Image Processing (ICIP)*, 2006, pp. 2311–2314.

[2] S. Bayram, I. Avcibas, B. Sankur, and N. Memon, "Image manipulation detection," *Journal of Electronic Imaging*, vol. 4, October-December 2006.

[3] M. Johnson and H. Farid, "Exposing digital forgeries by detecting inconsistencies in lighting," in *ACM Multimedia and Security Workshop*, 2005.

[4] A. Popescu and H. Farid, "Exposing digital forgeries in color filter array interpolated images," *IEEE Transactions on Signal Processing*, vol. 53, no. 10, pp. 3948–3959, 2005.

[5] A. Popescu and H. Farid, "Exposing digital forgeries by detecting traces of re-sampling," *IEEE Transactions on Signal Processing*, 2004.

[6] M. Kharrazi, H. T. Sencar, and N. Memon, "Blind source camera identification," in *IEEE International Conference on Image Processing*, October 2004, vol. 1, pp. 709–712.

[7] S. Bayram, H. T. Sencar, N. Memon, and I. Avcibas, "Source camera identification based on cfa interpolation," in *Proc. of IEEE ICIP*, 2005.

[8] A. Swaminathan, M. Wu, and K. J. Ray Liu, "Non-intrusive forensic analysis of visual sensors using output images," in *IEEE Conference on Acoustic, Speech and Signal Processing (ICASSP)*, France, May 2006, vol. 5, pp. 401–404.

[9] H. Farid and S. Lyu, "Higher-order wavelet statistics and their application to digital forensics," *Conference on Computer Vision and Pattern Recognition Workshop*, vol. 8, 2003.

[10] N. Tian-Tsong, C. Shih-Fu, H. Yu-Feng, X. Lexing, and T. Mao-Pei, "Physics-motivated features for distinguishing photographic images and computer graphics," in *ACM Multimedia*, Singapore, November 2005.

[11] Y. Wang and P. Moulin, "On discrimination between photorealistic and photographic images," in *IEEE International Conference on Acoustics, Speech and Signal Processing*. IEEE, May 2006, vol. 2, pp. II–161– II–164.

[12] J. Lukas, J. Fridrich, and M. Goljan, "Digital camera identification from sensor noise," *IEEE Transactions on Information Security and Forensics*, vol. 1, pp. 205–214, June 2006.

[13] R. Willson, M. Maimone, A. Johnson, and L. Scherr, "An optical model for image artifacts produced by dust particles on lenses," in *8th International Symposium on Artificial Intelligence, Robotics and Automation in Space (i-SAIRAS)*, September 2005.

[14] E. Steinberg, Y. Prilutsky, P. Corcoran, and et al., "Method of detecting and correcting dust in digital images based on aura and shadow region analysis," United States Patent Application Publication, March 2005, US Patent, 0068448 A1.

[15] Y. Morimoto, "Image processing method, an image processing apparatus, and a storage medium readable by a computer," United States Patent, September 2000, Patent number, 6,125,213.

[16] A. Krainiouk and R. T. Minner, "Method and system for detecting and tagging dust and scratches in a digital image," United States Patent, May 2001, Patent number, 6,233,364 B1.

[17] J. Lewis, "Fast normalized cross-correlation," in *Proc. of Vision Interface*, 1995.