

CELL PHONE IMAGES IN SOCIAL MEDIA:  
AN ANALYSIS OF CELLPHONE IMAGE STRUCTURE BEFORE AND AFTER SOCIAL  
MEDIA COMPRESSION

by

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Cell Phone Images in Social Media: An analysis of cellphone image structure before and after Social Media processing

Thesis directed by Associate Professor Catalin Grigoras

## **ABSTRACT**

Social media has made it easier than ever to publish pictures on the internet. Investigators now have to determine how to deal with pictures, posted to these social media websites, which become evidence in crimes. Traditional methods of authenticating the origin of pictures are not as effective because the processing applied by the social media websites eliminates or obscures much of this information. This thesis proposes several methods of image attribution that utilize popular image authentication techniques and presents test data to illustrate their use. Chapter 1 introduces to the topic of Image Attribution. Chapter 2 provides brief overview of the background analysis techniques that will be used. Chapter 3 describes how the test data that was taken and why. Chapter 4 proposes three different methods for answering three different forms of image attribution. Chapter 5 tests the reliability of the proposed methods with the cell phone image database uploaded to three separate social media websites. Chapter 6 provides a conclusion based on the results test results. Chapter 7 proposed future research in the field.

The form and content of this abstract are approved. I recommend its publication.

Approved: Catalin Grigoras

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## **CHAPTER I**

### **INTRODUCTION**

Social networking websites have become a group depository of personal photos for all to see. The public availability of these images provides evidence otherwise unavailable to law enforcement. However, this valuable investigative tool comes with its drawbacks.

There has not been much research done in images uploaded to social networking websites. Previous research has been done into the usefulness of artifacts left by social networking websites (Helenek) and a general survey of images that exist on Social Media websites. (Castiglione, Cattaneo and De Santis) No formal methods have been proposed to track images uploaded to social networking websites back to their origin.

This presentation will provide several methods to track the origin of images posted to social media websites. While Image Authentication techniques are traditionally used to determine the validity of images, some can be useful for determine the source of an image. According to the SWGIT Best Practices for Image Authentication, "Forensic Image Authentication is the application of image science and domain expertise to discern if a questioned image or video is an accurate representation of the original data by some defined criteria." This paper will differentiate methods of source identification as Image Attribution.

Traditional eye witnesses of crimes are being replaced by video and image recordings. Today, almost everyone owns a cellphone and crimes are being increasingly captured on cellphone cameras. Unlike the traditional camera, people always carry their cellphones and they are becoming increasingly user friendly. Due to proliferation and ease of use, cellphones are becoming increasingly important to law enforcement investigations.



As society is technologically evolving, evidence of crimes is increasingly posted to social networking websites. Investigators must determine where photos that find their way onto social networking websites originated. Investigators need to be able to trace exactly what social networking website an image came from and the camera that captured the image, however, the upload process makes it difficult for investigators to determine where uploaded images originate.

Cellphone cameras were chosen for this paper because each cell phone creates a photo in a unique way which is useful for image attribution. Several social networking websites were chosen because each alters uploaded images to normalize and reduce file size differently, providing a distinctive signature. Identifiers from the unique method that cellphone cameras use to capture photos and the distinctive signature produced by social networking websites are the basis of this study.

Three ways of attributing images to sources were proposed based on image authentication analysis techniques and distinctive social media processing features.

A database of cellphone camera images was prepared to provide a baseline for comparison and test images to determine the successfulness of the proposed Image Attribution methods. The database of images uploaded to social networking websites will be compared to determine distinctive signs of each one of the social networking websites uploading process.

The final results of this research will show that images uploaded to the internet can be identified given a sufficient database of images to compare and known identifiers of cellphone cameras and social networking website upload systems.

## **CHAPTER II**

### **IMAGE ATTRIBUTION TOOLS**

Image Manipulation has become easier since the advent of the computer and digital image editing software. Image Authentication provides a method of detecting image manipulation. Many of these techniques that are used to authenticate an image to an alleged source can also be used for Image Attribution. These techniques will be briefly covered in this chapter.

#### **Dimensional Analysis**

Dimensional analysis is the simplest of the Image Attribution methods. An image source creates a digital image with a fixed height and width. Some sources may allow for multiple dimensional settings. Comparing an image database, with all possible dimension settings for the image source established, against an unknown image's dimensions can establish a set of possible sources.

#### **Structure Analysis**

Structure Analysis relies on the way a source creates an image. Images analyzed in this project, JPEGs, adhere to a general structure making them universally readable. However, many aspects of the structure that can vary between sources or even be excluded all together. These structural variations can be combined to form signatures, which can be attributed to a capture device or image processing. However, capture device information is changed dramatically when sent through social media processing. This method is usually successful in attributing an image to the social media that it was processed by but not always the original source.

**Metadata Analysis**

Metadata analysis explores information imbedded in the image file data structure. Metadata can be read by simply looking for ASCII information in the hexadecimal code (Figure 9) or through an EXIF reader such the one built into Windows (Figure 1). A majority of the information that is embedding in JPEG images is indiscernible in ASCII and must be read with an EXIF reader. A typical capture device will provide a series of information that contains standard information such as the Camera Make and Model, as well as manufacturer specific information. A social media website may remove or alter this information to decrease file size and maintain user privacy. However, this processing can add its own metadata information, making it possible to attribute the image to the social media website.

Camera	
Camera maker	Apple
Camera model	iPhone 4
F-stop	f/2.8
Exposure time	1/1160 sec.
ISO speed	ISO-80
Exposure bias	
Focal length	4 mm
Max aperture	
Metering mode	Pattern
Subject distance	
Flash mode	No flash, auto
Flash energy	
35mm focal length	
GPS	
Latitude	39; 44; 33.60000000000056...
Longitude	104; 59; 4.20000000000115...
Altitude	1719.2405063291139

**Figure 1 Iphone 4 Metadata**

**Quantization Table Analysis**

Quantization Table Analysis relies on the way JPEG files determine compression level. Quantization Tables values control the amount of compression that is applied to an image. Two 8x8 quantization tables exist for each JPEG separately compressing the luminance and chrominance channels. The values of the 8x8 matrices can vary from 1 to

255 with higher values producing more compression. Figure 2 shows the two quantization tables (chrominance and luminance) contained in an original iPhone 4 image. Because the Quantization Tables have such a strong effect on subsequent image quality and file size, they vary considerably between sources. Since social media websites rely on small file sizes to decrease internet loading time, images from these sources are characterized by high quantization table values.

Luminance								Chrominance							
1	1	1	1	2	4	5	6	1	1	2	4	9	9	9	9
1	1	1	1	2	5	6	5	1	2	2	6	9	9	9	9
1	1	1	2	4	5	6	5	2	2	5	9	9	9	9	9
1	1	2	2	5	8	8	6	4	6	9	9	9	9	9	9
1	2	3	5	6	10	10	7	9	9	9	9	9	9	9	9
2	3	5	6	8	10	11	9	9	9	9	9	9	9	9	9
4	6	7	8	10	12	12	10	9	9	9	9	9	9	9	9
7	9	9	9	11	10	10	9	9	9	9	9	9	9	9	9

Figure 2 iPhone 4 Quantization Tables

### Compression Level Analysis

Quantization values determined by the Quantization Tables, is applied to the DCT coefficients of the image. This lossy process generates periodicity in the DCT coefficients. Compression Level Analysis focuses on this periodicity by analyzing the second derivative of the DCT coefficients. (Popescu and Farid, Statistical Tools for Digital Forensics) The traditional method of analysis is to visually analyze second derivative graphs as shown in Figure 3. A first generation JPEG image will produce a distinctive center spike with two minor spikes to the left and right. Subsequent compression will lead to many small spikes indicating increased periodicity due to the recompression. Each camera source will produce a distinctive frequency histogram and the location and shape of the spikes can be used to match a camera source image with a processed image. A database of known images from the camera is valuable as a point of comparison.

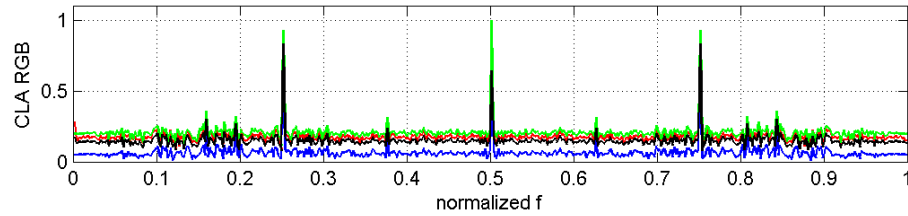


Figure 3 Mytouch 3g CLA

### Color Filter Array Analysis

Since traditional camera pixels only capture one of the three primary colors (red, green or blue), a Color Filter Array is used to capture an image with a combination of the three colors. The camera using a Color Filter Array, a mosaic of red, green and blue filters, captures a single color per pixel and then interpolates all red, green, and blue values based on neighboring pixels. (Popescu and Farid, Exposing digital forgeries in color filter array interpolated images) This interpolation produces periodicity unique to the color filter array used in the camera. Different color filter arrays use different combinations of red, green, and blue filter producing different frequencies in the histogram. The red, green, and blue histograms of the an uncompressed image are different from one another due to the placement and relative numbers of red, green and blue filters contained in the color filter array. Subsequent compression, which is done with the signal broken up into chrominance and luminance, will produce similarity between the red, green and blue histograms. Subsequent use of Color Filter Array did not provide any usable results for Image Attribution and its usage was scrapped from this project.

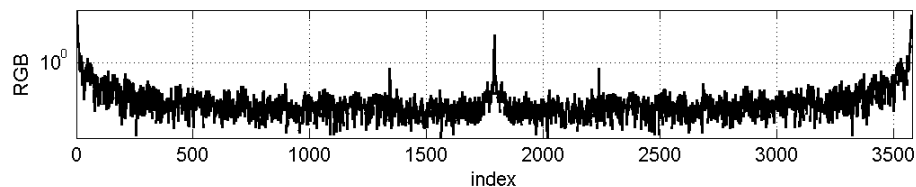
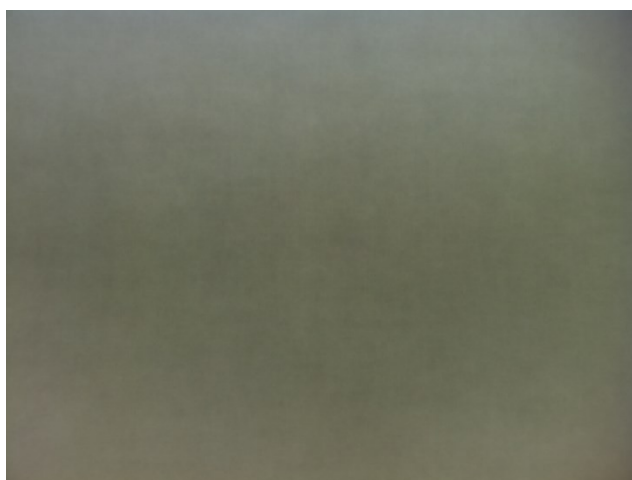


Figure 4 Mytouch 3g CFA

### **Photo Response Non-Uniformity Analysis**

Photo Response Non-Uniformity Analysis relies on the noise generated by the camera optics. Each camera model will contain different components leading to noise in the image captured. Even cameras within the same make and model will have varying noise signatures because of minor variation that occurs when producing camera imaging sensors. The Photo Response Non-Uniformity is best isolated by capturing several images from the same source and averaging them together. A proper set of images for PRNU requires good lighting and random scene content. PRNU is specific to the actual source camera used to take the picture due to the unique manufacturing error produced in every camera. (Lukas, Fridrich and Goljan) Figure 5 is an example of a PRNU sample generated from 1000 images that will be compared against test images.



**Figure 5 Iphone 4 PRNU sample generated from 1000 images**

## CHAPTER III

### TEST DATA

A database of cellphone camera images was compiled to test the proposed Image Attribution methods. These images were then uploaded to three social media websites, Facebook, Myspace, and Google Plus, to determine which unique signatures remained and what new signatures were formed for identification. The alterations done by the social media website image upload process were then recorded and compared against other social networking websites.

#### **Defining the Size of the Image Database**

The large corpus was captured for two reasons: to look for possible sources of error in the workflow and to provide enough images for high quality PRNU samples.

Using a large test corpus allowed me to find sources of error that may not have been present in a smaller dataset. Most of the processing chain in this project contains unknown 'black box' processes and only a large amount of images could say whether they worked as expected or not. The large test corpus showed many possible pitfalls a user might fall into when trying to perform image attribution in real casework. These errors are covered in more detail later on.

Working with such a large test corpus for this experiment was done also to determine how high of a PRNU match could be obtained with social media compressed images. Photo Response Non-Uniformity (PRNU) relies on the proper extraction of camera noise. Several images from the same camera are averaged together and filtered so that only the camera noise remains. Too small of a data set will result in a PRNU sample with scene details as well as the noise signature. This becomes less of an issue with larger data sets.

### **Taking the Original Pictures**

Creating the test corpus for this project can be broken down into several steps: capturing the images, choosing the social networking websites, uploading the image, and downloading the images.

Capturing images was done with strict criteria to ensure similar conditions for comparison. These criteria included GPS settings, orientation, and image content.

The camera settings were chosen based primarily on the default settings. In the cameras tested, this meant the highest quality and resolution settings. The only setting that was changed from default was the GPS location services. All phones with GPS location services had the feature turned on.

The orientation of the camera was controlled as well. All pictures were taken in landscape mode. The actual position of the camera varied between the side addressed and front addressed cameras. In front addressed cameras, such as the Blackberry 8650, pictures appear in landscape mode when the camera is positioned with the camera lens positioned at the top. In side addressed cameras, such as the iPhone 4, pictures appear in landscape mode when the camera lens is positioned to the side. This provides one realistic orientation for the front addressed cameras but two realistic orientations for the side addressed cameras. Typically a user will not take a picture with a front addressed camera with the camera positioned at the bottom. However, side addressed camera users may choose to take pictures with the camera lens to the left or the right. Most modern phones actually rotate the display based on the user's chosen orientation. This variation can cause issues with noise profile comparisons with evidence images. All pictures taken with side addressed cameras in the test corpus were taken with the camera lens on the left. If a picture was taken from the right, a 180° rotation can be performed for a proper noise profile comparison. Further orientation issues are discussed when social media processing is applied.



The image content of the pictures is important for PRNU analysis. All images were taken during the day, outdoors, with sufficient sunlight. This was done to limit the amount of spurious noise generated and provide a more varied intensity and color information. Because PRNU comparison is light dependent, similar lighting was used for database and mock evidence.

### **Choosing Social Networking Websites**

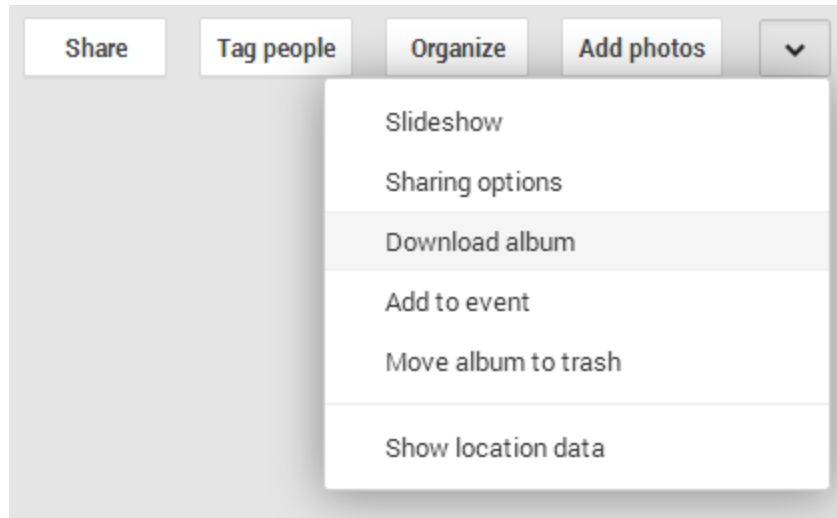
Three social networking websites were picked after early testing according to several criteria: a substantial user base, bulk upload capabilities, and bulk download capabilities.

The first criterion, a substantial user base, was established so that findings of this study would be useful for real life investigations. There are an endless number of social media websites available and it was not practical to include small user base websites in this study. Should data be required from other Social Networking Websites in the future, the principles and methodology of this experiment can be easily applied. The three social media websites chosen garner a large percentage of social media usage.

The second criterion, bulk upload capabilities, was established due to the size of the test corpus. With an input test corpus size of 9,900 pictures, uploading each image independently would be inefficient. The three social media websites chosen allow for bulk image upload. Tumblr was originally considered but was eliminated due to a lack of bulk uploading capabilities and a daily upload limit.

The third criterion, bulk download capabilities, was also established due to the size of the test corpus but was later relaxed. Two of the social networking websites, Google Plus and Facebook, allow for bulk downloads. The Google Plus' bulk download feature, Download album, is shown in Figure 6. The third website, Myspace, restricted the bulk download feature to law enforcement. A third-party bulk download software was used to

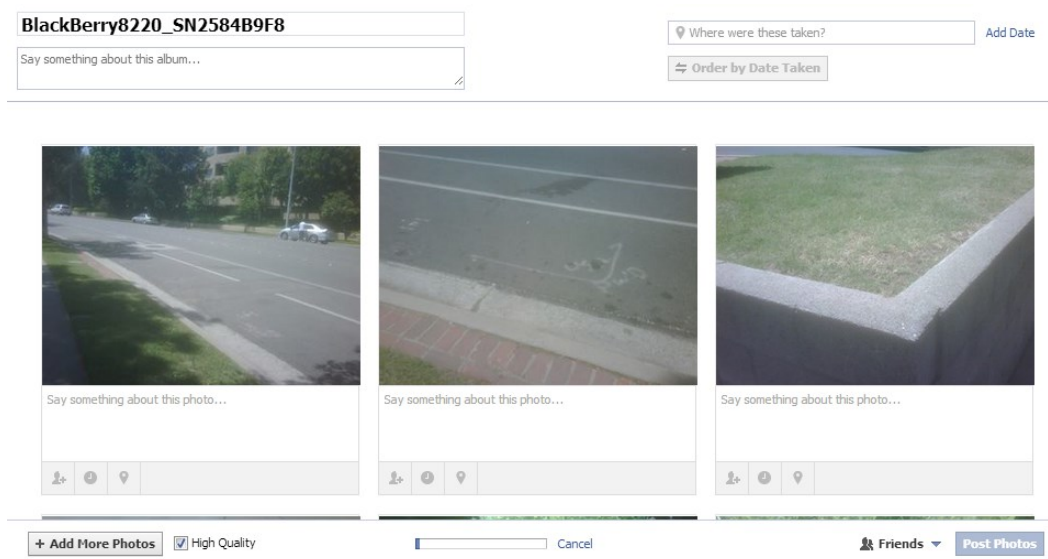
acquire images from Myspace. Further explanation of this process will be provided later on.



**Figure 6 Google Plus Download Album Feature**

### **Uploading to Social Media Websites**

Uploading the images was done with each social media website's standard PC upload interface. This was done to mimic the traditional method that a user would use to upload images and to ensure no further processing was done by 3rd party software. 1,100 images were uploaded to Facebook, Myspace and Google Plus from each of the 9 cameras. Images were uploaded in 100 image sets to avoid size restrictions and upload errors. All three social networking websites produced upload errors in which an image was uploaded twice or an image was not uploaded at all. These errors were rare and were fixed manually by deleting duplicates and uploading missing images. Google Plus and Myspace provided no options for customizing the upload quality but Facebook allowed for 'High Quality' as seen in Figure 7. 'High Quality' was chosen for all images uploaded to Facebook. Disabling 'High Quality' was not pursued in this project.



**Figure 7 Facebook image upload interface**

### **Downloading from Social Media Websites**

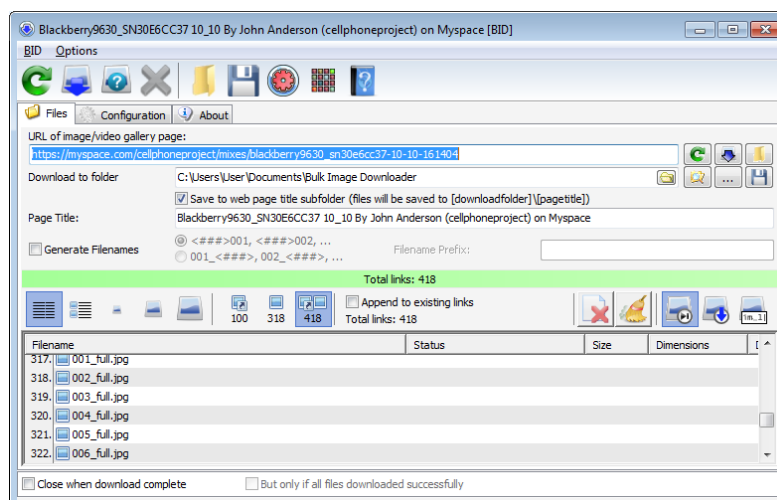
Downloading the images was done differently for each social media website because each website had different download options. Google Plus allows for album and archive download, Facebook allows for archive download, and Myspace provided no bulk image download options available to the general public.

Google Plus provided the easiest bulk image download with both a single album and archive download. A photo archive was available through Google's Takeout service. However, when downloaded, the photo archive contained an incomplete collection of the images uploaded to Google Plus. Subsequently, the single album download feature in Google Plus was used and all albums were downloaded without incident.

Facebook provided an archive download which among other data, was supposed to include all photos taken on the account. This archive included a multitude of account information but similar to the Google Takeout had an incomplete archive of photos. Without a single album download function, images were downloaded one at a time. This however was found not to be optimal because some images are displayed in a lower

resolution than what was available through the archive download. Once this was determined, photos that were included in the archive were deleted from the Facebook account so that the missing images would be provided in a subsequent archive download. This was repeated several times, and several albums were downloaded. After several repeated archive download, the archive download stopped downloading correctly. Another Facebook account was created, and the rest of the albums were downloaded from this secondary account. Technical support inquiries provided no useful explanation for the archive download issues.

Myspace provided no archive download of any kind to the general public. Myspace only provides archive downloads with a legal request. Myspace required that images be downloaded independently. A third party bulk image downloader was used to perform this function shown in Figure 8. The program's output was verified to be identical to images manually downloaded.



**Figure 8 Bulk Image Downloader interface**

## CHAPTER IV

### METHOD

In an image attribution investigation, there are three possible questions asked: What social media was an image processed with, what camera model was the image captured with, and can the specific camera be matched? This chapter will propose methods for answering each of these questions.

#### **Social Media Website Image Attribution**

The first question, “what social media was an image processed with?”, involves looking for similarities between all images uploaded to a single social network website. This type of analysis is most important for investigative use. Determining the source of an unknown image can lead to further evidence, a higher resolution version of the image, and more information about the image itself. The information used for Social Media Website Image Attribution are metadata information, image dimensions, file structure and quantization tables. Overall this analysis is the least complicated and time-consuming especially if you already have a database of known identifiers.

Image metadata is information written into images that provides details about an image, such as the Make and Model of the capture device or the GPS location where the image was taken. Cellphone images were chosen as the test corpus partially because they contain a large amount of metadata information. A sample of the information contained in a cellphone image is provided in Figure 9 from a hex viewer. Each row shows information from the byte offset designated on the far left. The first column next to the byte offset show the hexadecimal representation at the particular byte offset, the second column shows the ASCII representation and the third column provides a

description of the contents of each offset.

-000c		ff d8 ff e1	3f fe 45 78 69 66 00 00	....?.Exif..	JPEG header APP1 header Exif header
0000	4d 4d 00 2a 00 00 00 08	00 0b		MM.*.....	TIFF header IFD0 entries
000a	01 0f 00 02 00 00 00 06	00 00 00 92		.....	IFD0-00 Make
0016	01 10 00 02 00 00 00 09	00 00 00 98		.....	IFD0-01 Model
0022	01 12 00 03 00 00 00 01	00 01 00 00		.....	IFD0-02 Orientation
002e	01 1a 00 05 00 00 00 01	00 00 00 a2		.....	IFD0-03 XResolution
003a	01 1b 00 05 00 00 00 01	00 00 00 aa		.....	IFD0-04 YResolution
0046	01 28 00 03 00 00 00 01	00 02 00 00		.(.....	IFD0-05 ResolutionUnit
0052	01 31 00 02 00 00 00 04	35 2e 31 00		.1.....5.1.	IFD0-06 Software
005e	01 32 00 02 00 00 00 14	00 00 00 b2		.2.....	IFD0-07 ModifyDate
006a	02 13 00 03 00 00 00 01	00 01 00 00		.....	IFD0-08 YCbCrPositioning
0076	87 69 00 04 00 00 00 01	00 00 00 c6		.i.....	IFD0-09 ExifOffset
0082	88 25 00 04 00 00 00 01	00 00 02 4c		.\$.....L	IFD0-10 GPSInfo
008e		00 00		..	Next IFD
0090	03 16 41 70 70 6c 65 00	69 50 68 6f 6e 65 20 34		..Apple.iPhone 4	Make value
00a0	00 00 00 00 48 00 00	00 01 00 00 00 48 00 00		....H.....H..	Model value [pad byte] XResolution value
00b0	00 01 32 30 31 32 3a 30	37 3a 31 34 20 31 33 3a		..2012:07:14 13:53:17...	YResolution value
00c0	35 33 3a 31 37 00 00 18			53:17...	ModifyDate value ExifIFD entries
00c8	82 9a 00 05 00 00 00 01	00 00 01 ec		.....	ExifIFD-00 ExposureTime
00d4	82 9d 00 05 00 00 00 01	00 00 01 f4		.....	ExifIFD-01 FNumber
00e0	88 22 00 03 00 00 00 01	00 02 00 00		."	ExifIFD-02 ExposureProgram
00ec	88 27 00 03 00 00 00 01	00 50 00 00		.'.....P..	ExifIFD-03 ISO
00f8	90 00 00 07 00 00 00 04	30 32 32 31		.....0221	ExifIFD-04 ExifVersion
0104	90 03 00 02 00 00 00 14	00 00 01 fc		.....	ExifIFD-05 DateTimeOriginal
0110	90 04 00 02 00 00 00 14	00 00 02 10		.....	ExifIFD-06 CreateDate
011c	91 01 00 07 00 00 00 04	01 02 03 00		.....	ExifIFD-07 ComponentsConfiguration
0128	92 01 00 0a 00 00 00 01	00 00 02 24		.....\$	ExifIFD-08 ShutterSpeedValue
0134	92 02 00 05 00 00 00 01	00 00 02 2c		.....,	ExifIFD-09 ApertureValue
0140	92 03 00 0a 00 00 00 01	00 00 02 34		.....4	ExifIFD-10 BrightnessValue
014c	92 07 00 03 00 00 00 01	00 05 00 00		.....	ExifIFD-11 MeteringMode
0158	92 09 00 03 00 00 00 01	00 18 00 00		.....	ExifIFD-12 Flash
0164	92 0a 00 05 00 00 00 01	00 00 02 3c		.....<	ExifIFD-13 FocalLength
0170	92 14 00 03 00 00 00 04	00 00 02 44		.....D	ExifIFD-14 SubjectArea
017c	a0 00 00 07 00 00 00 04	30 31 30 30		.....0100	ExifIFD-15 FlashpixVersion
0188	a0 01 00 03 00 00 00 01	00 01 00 00		.....	ExifIFD-16 ColorSpace
0194	a0 02 00 04 00 00 00 01	00 00 0a 20		.....	ExifIFD-17 ExifImageWidth
01a0	a0 03 00 04 00 00 00 01	00 00 07 90		.....	ExifIFD-18 ExifImageHeight
01ac	a2 17 00 03 00 00 00 01	00 02 00 00		.....	ExifIFD-19 SensingMethod
01b8	a4 02 00 03 00 00 00 01	00 00 00 00		.....	ExifIFD-20 ExposureMode
01c4	a4 03 00 03 00 00 00 01	00 00 00 00		.....	ExifIFD-21 WhiteBalance
01d0	a4 06 00 03 00 00 00 01	00 00 00 00		.....	ExifIFD-22 SceneCaptureType
01dc	a4 0a 00 03 00 00 00 01	00 02 00 00		.....	ExifIFD-23 Sharpness
01e8		00 00 00 00 00 00 00 01		.....	Next IFD
01f0	00 00 01 a9 00 00 00 0e	00 00 00 05 32 30 31 32		.....2012	ExposureTime value FNumber value
0200	3a 30 37 3a 31 34 20 31	33 3a 35 33 3a 31 37 00		:07:14 13:53:17.	DateTimeOriginal value
0210	32 30 31 32 3a 30 37 3a	31 34 20 31 33 3a 35 33		2012:07:14 13:53	CreateDate value
0220	3a 31 37 00 00 00 25 61	00 00 04 48 00 00 10 b9		:17...\$a...H....	ShutterSpeedValue value

Figure 9 Metadata displayed by ExifToolGUI

Determining the source of an image with original metadata information intact is relatively easy with the Make and Model included. Information can be interpreted in JPEG images with an Exif reader as shown in Figure 10. This is especially useful for metadata that is not written in ASCII. However, social media websites modify image metadata, eliminating most of the information. This makes determining the camera source difficult but provides a tool for determining the social media website that the image was processed with. Each social media website studied so far removes and adds different information allowing for easy identification.

Make	Apple
Model	iPhone 4
Orientation	Horizontal (normal)
XResolution	72
YResolution	72
ResolutionUnit	inches
Software	5.1
ModifyDate	2012:07:14 13:53:17
YCbCrPositioning	Centered
	---- ExifIFD ----
ExposureTime	1/425
FNumber	2.8
ExposureProgram	Program AE
ISO	80
ExifVersion	0221
DateTimeOriginal	2012:07:14 13:53:17
CreateDate	2012:07:14 13:53:17
ComponentsConfiguration	Y, Cb, Cr, -
ShutterSpeedValue	1/425
ApertureValue	2.8
BrightnessValue	7.765796703
MeteringMode	Multi-segment
Flash	Auto, Did not fire
FocalLength	3.9 mm
SubjectArea	1295 967 699 696
FlashpixVersion	0100
ColorSpace	sRGB
ExifImageWidth	2592
ExifImageHeight	1936

**Figure 10** Further information can be decoded from the imbedded Exif information.

Modern cameras have evolved over time to produce larger resolution images in order to increase the possible overall quality of the image. Large resolution images become important if you want to crop or print an image. However, internet images are produced as small as possible to limit the file size and because most people only want to view images on the internet in a fraction of their original resolution. Social Media Websites compensate for large resolution uploaded images by resizing them. Some social media websites even adjust the relative width and height of images called the

aspect ratio. Since each social media website resizes images differently, knowledge of each website's image dimensions can be used to determine which social media an image was processed with.

Most cellphone images are JPEG compressed files. JPEG files use quantization tables to determine how much compression is to be applied to an image. Two quantization tables exist, chrominance and luminance, and every time a JPEG file is saved, quantization tables are applied. Each quantization table contains an 8x8 matrix of values that can be assigned a value from 1 to 255. Camera manufacturers define what quantization tables are used in a camera and vary between Make and Model. Social media websites do not retain these values when the images are processed. Instead images are given new quantization tables defined by the social media website when processed. Knowing the quantization tables used by a social networking website can be used to determine which one was used to process an image.

### **Camera Model Image Attribution**

The second question, "what camera model was the image captured with?", involves looking for image identifiers that haven't been eliminated by Social Media processing. This method is useful for focusing investigations, eliminating potential suspects, producing possible timelines, and even weak multiple image association. The information used for Camera Model Image Attribution is left over metadata, supporting social media documents and Compression Level Analysis (CLA). A basic analysis of metadata and social media documents is not complicated or time-consuming while CLA analysis is more difficult.

Each social media website will remove and add its own metadata. By understanding what information is generated by the social media website, the user can look for any



metadata that has been left over from the original camera. Some social media websites will leave no original metadata while others will leave the original metadata mostly intact.

Social media websites record user usage and store it in an archive. This information is typically only available to law enforcement with a court order. This information will usually contain information such as when the account was logged into and what IP addresses were used. However, some social media websites capture the metadata information of the camera prior to modifying it.

Of the three social media website I looked at, Facebook was the only one that provided image metadata information to the account owner without a court order. This information included the date/time the image was taken, location image was taken, and image capture parameters if the original camera image contain the information. An example of this information is provided in Figure 11.

#### **lphone4\_SN86025XUGA4S HQ Part 1/10**



Date Taken: July 23, 2012 at 7:17 am  
Latitude: 39.7323333333  
Longitude: -104.961  
Orientation: 1  
Camera Model: iPhone 4  
Exposure: 1/256  
F-Stop: 14/5  
ISO Speed: 80  
Focal Length: 77/20

February 10, 2013 at 6:02 pm

**Figure 11 Camera Metadata information from a Facebook archive download**

### **Specific Camera Image Attribution**

The third question, “can the specific camera be matched?”, involves looking primarily at Photo Response Non-uniformity (PRNU). This question is the most difficult because test images must be taken with the specific camera in question. This is often problematic when there are multiple suspected cameras or the evidence camera is inaccessible.

When a large number of suspect phones exist, it is advised that the investigator first perform Camera Model Image Attribution analysis to determine the model of specific camera.

PRNU analysis works best for Specific Camera Image Attribution because it focuses on optic noise which typically varies between cameras of the same model.

## CHAPTER V

### RESULTS

#### Overview

A test corpus of 1000 images per camera was used as the database and a smaller independent set of 100 images was used as the mock evidence. In this test, multiple signatures were used to increase the robustness of the methods but can be excessive especially in many investigative applications.

**Note:** *Although some of the methods included are complicated and may be beyond the technical skills of the base investigator, many of the simple tools provided can often be all that is needed to attribute an image. It is also important to note that Social Media processing is a 'black box' processing, meaning that there is no published explanation of the process that input images go through. This means that when performing an authentication/attribution analysis, there is a possibility that all possible outputs are not accounted for in testing. Furthermore, it is important to note that the processing may change depending on modifications made by the Social Media Website to the processing algorithm over time. Old assumptions should be verified to ensure they still hold true.*

Below, the test pictures were compared, helping determine the answer to the three image attribution questions:

#### Social Media Website Image Attribution

Metadata from known Social Media Website source images was compared to their known originals and several determinations were made. When an image is uploaded to social media, a majority of its metadata is replaced. Figure 12 illustrates how a section of metadata can change dramatically between the Original and Social Media processed.

The important thing to notice is that each website produces a slightly different signature, providing a simple low-level analysis of Social Media Website Image Attribution.

Signatures can be found by uploading exemplar images to each social media website and comparing image before and after.

Images uploaded to Myspace have their original metadata completely replaced. First, you will notice that the APP0 JFIF segment denoted with an ASCII phrase 'JFIF'. This metadata was added by all social network websites used in this project but was not included with any original images from cellphones. Additionally, in the Myspace uploaded images, several other segments are understandable in ASCII. 'Copyright International Color Consortium, 2009' is one of the ASCII segments and was found in all of images uploaded to Myspace regardless of source. Facebook also replaces metadata with the same JFIF and ASCII segments. However, Facebook images can be differentiated from Myspace images by the COM Comment segment found directly proceeding the APP0 JFIF segment with a recognizable '\*' ASCII symbol. Myspace images do not contain the COM Comment segment.



The second unusual field is an APP1 XMP segment that contains an adobe and w3 URL. This entry was also only found in images uploaded with Google Plus. Several other entries can be used for Social Media Website Image Attribution but they vary depending on the contents of the original metadata. The ExifIFD ImageUniqueID entry appears in all Google Plus uploaded images. The ImageUniqueID values are different for each image and no correlation has been found between the values. The ImageUniqueID entry was also found in original HTC Trophy images. The HTC Trophy ImageUniqueID value entry was changed when uploaded to Google Plus. It is important to understand the original metadata of an image before using the ImageUniqueID to attribute an image to Google Plus.

The another method of attributing images to a Social Media only works for original images that are missing standard metadata. Some images lack standard metadata tags and Google Plus will add the tags during processing if they are not found in the original image. The most important of these tags is the Software tag because an added tag actually contains a 'Picasa' value that can also identify Google Plus. However, if an image already contains one of these standard metadata tags, the information will not be replaced.

The last way to attribute an image to Social Media is through the thumbnail. If an original image does not contain a thumbnail, Google Plus will add one. Also, Google Plus restricts the thumbnail size of an image to width of 160. The height will depend on the aspect ratio of the original thumbnail or full image. Metadata information can be very useful but care should be taken when considering analyzing metadata because metadata can be easily tampered, so other attribution methods should be used to verify.

Social Media websites process images for two reasons: reducing file storage requirements and providing the user with a faster load time. Every new generation of cameras is providing a higher and higher number of pixels making file size and load time

bigger and longer. The simplest way Social Media websites eliminate this issue is to resize the image. Multiple versions of the same image are created to accommodate desktop, cell phone and tablet access. Even more versions are created for album thumbnails, timeline backgrounds, profile pictures, etc. In this test, the highest resolution images were used to facilitate the statistical data comparisons. However, the full resolution images are not always resized. Social Media Websites only resize images when they pass a designated pixel threshold. Castiglione et Al. performed an analysis on the pixel thresholds for Facebook and Google Plus and determined that the threshold was at 2048 x 2048 for Facebook with the High Quality setting and 2048 x 2048 for Google Plus as well. For example, the iPhone 4 original has a resolution of 2592 x 1936. Facebook resized the image to 2048 x 1530 which can identify the Social Media source from the original but not from all other Social Media because Myspace and Google Plus also provided the same dimensions. However, preliminary research done with Tumblr showed iPhone images being resized to 1280 x 956. Dimensional analysis can give clues to the Social Media Image Attribution Social Media website depending on the upload website and original image dimensions. A full chart of dimensional resizing of the test data is provided in Figure 13. Also, in real world applications, non-full resolution images can more easily be traced back to their Social Media source based on their more irregular sizes.

Camera	Original	Google +	Facebook	MySpace
iPhone 3gs	2048 x 1538	2048 x 1536	2048 x 1536	2048 x 1536
iPhone 4	2592 x 1936	2048 x 1530	2048 x 1530	2048 x 1530
HTC myTouch 3G	2048 x 1536	2048 x 1536	2048 x 1536	2048 x 1536
HTC Trophy	2592 x 1944	2048 x 1536	2048 x 1536	2048 x 1536
HTC EVO 4G	3264 x 1952	2048 x 1225	2048 x 1225	2048 x 1225
BB Pearl Flip	1600 x 1200	1600 x 1200	1600 x 1200	1600 x 1200
BB Curve	1600 x 1200	1600 x 1200	1600 x 1200	1600 x 1200
BB Tour	2048 x 1536	2048 x 1536	2048 x 1536	2048 x 1536
Moto Cliq	2560 x 1920	2048 x 1536	2048 x 1536	2048 x 1536

**Figure 13 Image Dimensions after Social Media resizing**

Another way in which many social media websites deal with long image loading times is to change the way the image is loaded all together. A traditional JPEG image is formatted as Baseline and the entire image is encoded in one scan and the image is loaded by the end-user all at once. However, a more efficient method, Progressive, encodes the image in multiple passes allowing users on slower connections to see the image earlier than a Baseline image. The eventual image is the same and the conversion can be done with no loss of quality. Traditionally, cameras take pictures with Baseline encoding and only some Social Media Websites use Progressive. Facebook and Myspace use Progressive encoding while Google Plus and Tumblr use Baseline encoding. It can be difficult to determine whether an image is Baseline or Progressive encoded with traditional tools but there are many freeware tools available that provide this information, such as JPEG Snoop and Exiftool.

Resizing only limits the number of pixels in an image, the true ability of a Social Media Website's to optimize storage and load time is with lossy JPEG compression. The central tool for this lossy compression is the JPEG Quantization Tables that determine how much compression is applied to the image. Because this step has a large impact on the eventual quality of the image, camera manufacturers and Social Media websites



choose different values for the 2 8x8 value tables to best optimize quality vs. file size. Though these values are not always unique from camera to camera, in traditional camera authentication, Quantization Tables can be used to eliminate a camera as a 'suspect' if it is unable to produce the Quantization Tables in question. Cameras have traditionally provided static Quantization Tables, meaning that images taken with the same camera with the same quality settings will always have the same Quantization Tables. However, Social Media websites do not follow the same model. Google Plus provides several Quantization Tables values but only one set of Thumbnail Quantization Tables regardless of the capture source. In Figure 14, the Google Plus Blackberry 8220 image and the Iphone 4 image have different Quantization Tables but identical Thumbnail Quantization Tables. Facebook provides several possible tables which presumably are applied according to image content. Figure 15 shows several possible Facebook Blackberry 8220 Quantization Tables with Quantization Table 2 matching the Blackberry 8220 test image. Though Quantization Tables may vary from image to image, the limited number of tables used by Facebook allows for Social Media Website Image Attribution. Myspace provides a single Quantization Table for all images. Figure 16 shows several Myspace images sharing the same Quantization Tables. Each of the image sources have different features but they can each be used for Social Media Website Image Attribution as long as a trend can be determined.

Google Plus Blackberry 8220 Quantization Table															
Luminance								Chrominance							
3	2	10	10	10	8	8	8	3	4	6	10	12	12	12	12
2	10	10	8	8	8	8	8	4	5	6	13	12	2	12	12
10	10	10	10	8	8	8	8	6	6	12	13	12	12	12	12
10	10	8	8	8	8	8	8	10	13	15	13	12	12	12	12
10	8	8	8	8	10	10	8	15	15	13	12	12	12	12	12
8	8	8	8	8	10	12	8	15	15	13	12	12	12	12	12
8	8	8	8	10	12	12	8	13	12	12	12	12	12	12	12
8	8	8	8	10	8	10	8	13	13	13	12	12	12	12	12





Myspace Motorola Cliq															
Luminance								Chrominance							
5	3	3	5	7	12	15	18	5	5	7	14	30	30	30	30
4	4	4	6	8	17	18	17	5	6	8	20	30	30	30	30
4	4	5	7	12	17	21	17	7	8	17	30	30	30	30	30
4	5	7	9	15	26	24	19	14	20	30	30	30	30	30	30
5	7	11	17	20	33	31	23	30	30	30	30	30	30	30	30
7	11	17	19	24	31	34	28	30	30	30	30	30	30	30	30
15	19	23	26	31	36	36	30	30	30	30	30	30	30	30	30
22	28	29	29	34	30	31	30	30	30	30	30	30	30	30	30

Myspace Apple Iphone 4															
Luminance								Chrominance							
5	3	3	5	7	12	15	18	5	5	7	14	30	30	30	30
4	4	4	6	8	17	18	17	5	6	8	20	30	30	30	30
4	4	5	7	12	17	21	17	7	8	17	30	30	30	30	30
4	5	7	9	15	26	24	19	14	20	30	30	30	30	30	30
5	7	11	17	20	33	31	23	30	30	30	30	30	30	30	30
7	11	17	19	24	31	34	28	30	30	30	30	30	30	30	30
15	19	23	26	31	36	36	30	30	30	30	30	30	30	30	30
22	28	29	29	34	30	31	30	30	30	30	30	30	30	30	30

Figure 16 Images uploaded to Myspace share the same Quantization Tables

Some modifications by Social Media websites actually change the overall file structure of the image. In Figure 17, Facebook and Myspace processing dramatically changes the structure of the image. The major reason for the huge variation in file structure is due to changing the image from Baseline to Progressive. A Baseline image requires less Huffman Tables and only one start of scan. A Progressive image breaks up the image into multiple scans which is more conducive for internet/mobile viewing. We noted earlier that the conversion from Baseline to Progressive is lossless and this is because unlike Quantization Tables that are inherently lossy, the Huffman Tables that are added are a lossless transform. Facebook and Myspace processed images are both progressive but Figure 17 shows Facebook processed images have one more Huffman Table than Myspace processed images. Figure 17 also shows that Google Plus remains Baseline and the structure changes primarily due to the addition of a thumbnail image. The file structure analysis of the eight other camera sources is provided in Appendix A.

The structure of each of the images after social media processing maintains the social media specific structure.

<p>0 -&gt; FFD8 = JPEG Start [0]  2 -&gt; FFE1 = APP  1B0 -&gt; FFDB = Quantization Table  1F5 -&gt; FFDB = Quantization Table  23A -&gt; FFC4 = Huffman Table  25B -&gt; FFC4 = Huffman Table  312 -&gt; FFC4 = Huffman Table  333 -&gt; FFC4 = Huffman Table  3EA -&gt; FFC0 = Baseline DCT  3FD -&gt; FFDA = Start of Scan (SOS)  53046 -&gt; FFD9 = JPEG End [53046]</p>	(a)	<p>0 -&gt; FFD8 = JPEG Start [0]  C0E -&gt; FFDB = Quantization Table  C53 -&gt; FFDB = Quantization Table  C98 -&gt; FFC2 = Progressive DCT  CAB -&gt; FFC4 = Huffman Table  CC7 -&gt; FFC4 = Huffman Table  CE1 -&gt; FFDA = Start of Scan (SOS)  53AE -&gt; FFC4 = Huffman Table  53DA -&gt; FFDA = Start of Scan (SOS)  9D68 -&gt; FFC4 = Huffman Table  9D8D -&gt; FFDA = Start of Scan (SOS)  A112 -&gt; FFC4 = Huffman Table  A138 -&gt; FFDA = Start of Scan (SOS)  A75C -&gt; FFC4 = Huffman Table  A78A -&gt; FFDA = Start of Scan (SOS)  B353 -&gt; FFC4 = Huffman Table  B37D -&gt; FFDA = Start of Scan (SOS)  1578C -&gt; FFDA = Start of Scan (SOS)  16DA1 -&gt; FFC4 = Huffman Table  16DC3 -&gt; FFDA = Start of Scan (SOS)  1901C -&gt; FFC4 = Huffman Table  1903F -&gt; FFDA = Start of Scan (SOS)  1B71D -&gt; FFC4 = Huffman Table  1B745 -&gt; FFDA = Start of Scan (SOS)  37B5A -&gt; FFD9 = JPEG End [37B5A]</p>	(c)
<p>0 -&gt; FFD8 = JPEG Start [0]  C14 -&gt; FFDB = Quantization Table  C59 -&gt; FFDB = Quantization Table  C9E -&gt; FFC2 = Progressive DCT  CB1 -&gt; FFC4 = Huffman Table  CCD -&gt; FFC4 = Huffman Table  CE6 -&gt; FFC4 = Huffman Table  CFF -&gt; FFDA = Start of Scan (SOS)  4BD8 -&gt; FFC4 = Huffman Table  4C01 -&gt; FFDA = Start of Scan (SOS)  7BB7 -&gt; FFC4 = Huffman Table  7BDC -&gt; FFDA = Start of Scan (SOS)  7C7D -&gt; FFC4 = Huffman Table  7CA0 -&gt; FFDA = Start of Scan (SOS)  7E2A -&gt; FFC4 = Huffman Table  7E55 -&gt; FFDA = Start of Scan (SOS)  8219 -&gt; FFC4 = Huffman Table  8244 -&gt; FFDA = Start of Scan (SOS)  1033C -&gt; FFDA = Start of Scan (SOS)  11952 -&gt; FFC4 = Huffman Table  11975 -&gt; FFDA = Start of Scan (SOS)  13074 -&gt; FFC4 = Huffman Table  13096 -&gt; FFDA = Start of Scan (SOS)  14CE1 -&gt; FFC4 = Huffman Table  14D0A -&gt; FFDA = Start of Scan (SOS)  266B8 -&gt; FFD9 = JPEG End [266B8]</p>	(b)	<p>0 -&gt; FFD8 = JPEG Start [0]  14 -&gt; FFE1 = APP  262 -&gt; FFD8 = JPEG Start [262]  276 -&gt; FFDB = Quantization Table  2BB -&gt; FFDB = Quantization Table  300 -&gt; FFC0 = Baseline DCT  313 -&gt; FFC4 = Huffman Table  330 -&gt; FFC4 = Huffman Table  368 -&gt; FFC4 = Huffman Table  383 -&gt; FFC4 = Huffman Table  3A2 -&gt; FFDA = Start of Scan (SOS)  13FA -&gt; FFD9 = JPEG End [13FB]  13FC -&gt; FFE1 = APP  1520 -&gt; FFDB = Quantization Table  15A6 -&gt; FFC0 = Baseline DCT  15B9 -&gt; FFC4 = Huffman Table  15D7 -&gt; FFC4 = Huffman Table  1623 -&gt; FFC4 = Huffman Table  163F -&gt; FFC4 = Huffman Table  1673 -&gt; FFDA = Start of Scan (SOS)  40E96 -&gt; FFD9 = JPEG End [40E96]</p>	(d)

Figure 17 File Structure after social media processing  
(a) Blackberry 8220 Original (b) Facebook Processed (c) Myspace Processed (d) Google Plus Processed

### **Camera Model Image Attribution**

Camera Model Image Attribution follows a similar model to Social Media Website Image Attribution. Analysis always starts with the simplest techniques and gradually gets more technically and computationally complex. Camera Model Image Attribution will involve metadata, supporting social media documents and Compression Level Analysis (CLA).

The first information to look at is the metadata. In Social Media Website Image Attribution, the focus of the analysis was on the information added by the Social Media processing. In Camera Model Image Attribution, the focus of the analysis is on the information that was left behind from before the Social Media processing. In the previous section it was noted that most of the original information is removed from the image. This is typically the case with most sources. Facebook and Myspace are among the sources that eliminate camera information in the metadata. Google Plus and Tumblr retain some camera information allowing for attribution. Images from Facebook and Myspace will provide no metadata information useful for Camera Model Image Attribution. However, it is fairly easy to determine the camera source of Google Plus and Tumblr images because part of the information retained is the Camera Make and Model. Original images that contain Software entries can also be linked to the Google Plus or Tumblr with the particular operating system that is used by the phone. Original images that contain any type of time entries such as ModifyDate, DateTimeOriginal or CreateDate can be used to attribute if any original time information is known. However, Google Plus and Tumblr were the only websites tested that retained time information. It again should be noted that metadata can be easily tampered with but other attribution methods can be used to verify.

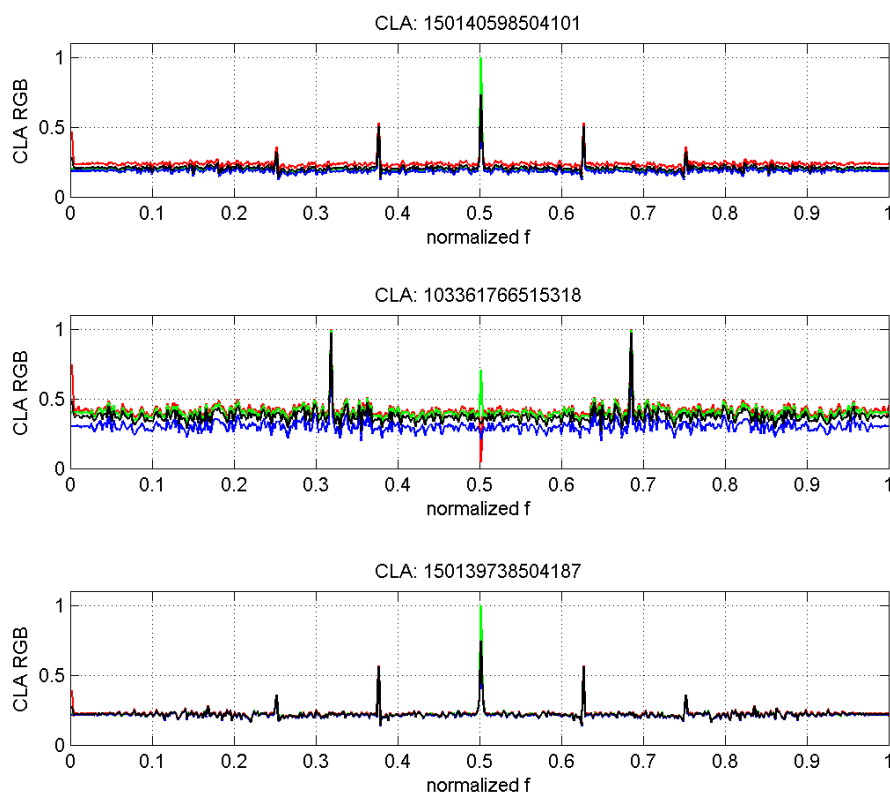
Many Social Media websites store account usage statistics. Facebook, Google Plus, and Myspace all provide options for law enforcement to obtain information with the

proper court order. (Facebook) (Google) (Myspace) However, none of these resources divulge what sort of information is provided to law enforcement. The only glimpse into the content contained in these reports comes from Facebook's user account archive download feature that provides a plethora of information including message history, login locations, IP Addresses, Searches, and more. What is interesting for Image Attribution, is that they provide photo metadata. When Facebook eliminates the original metadata information, it actually keeps a portion of the information that can be downloaded in an archive by the owner of the account or by law enforcement. An example of this information is provided in Figure 11. Depending on the image source, different information is included but in all of the tests performed, the camera model was always included. The complete collection of Facebook extracted social media metadata is included in Appendix B.

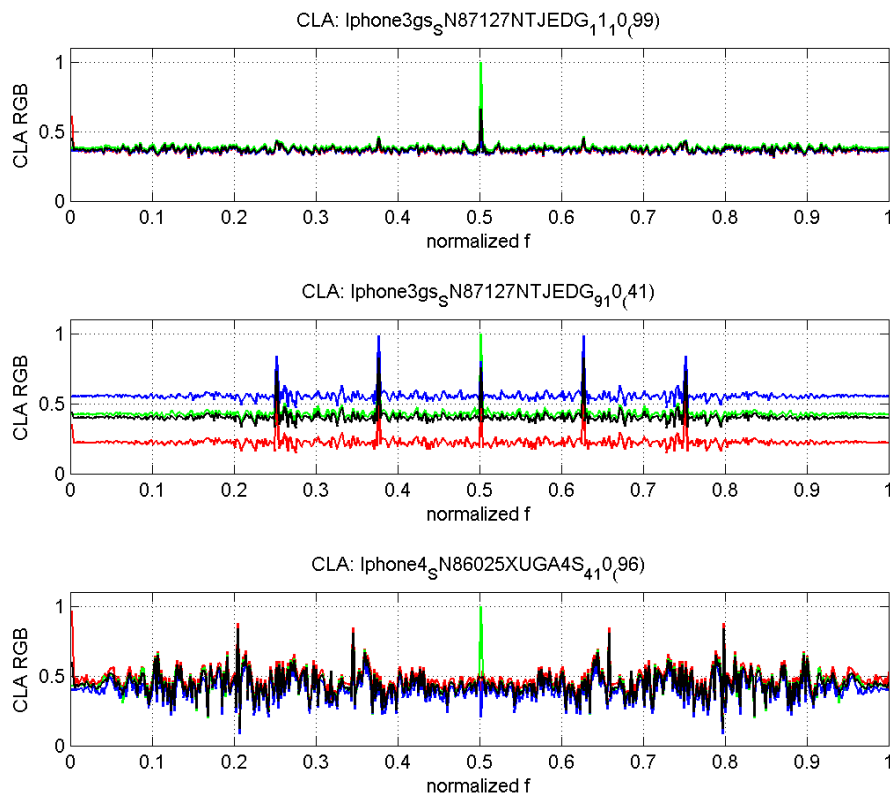
Compression Level Analysis (CLA) utilizes the distinctive shape of the second derivative in JPEG compressed images to match an unknown image to a known source. The traditional method involves comparing the shape of CLA graphs of two signals. This comparison can be seen in Figure 18. The first graph, (a), is an unknown image from Facebook. Two comparison images from Facebook are shown: (b) is a Iphone 4 image and (c) is a Blackberry 9630 image after Facebook processing. Visual comparison shows that (a) and (c) are the same image. However, sometimes the Social Media images are more difficult to match visually. Some visual comparisons look like Figure 19 instead. The first graph, (a), is an unknown image from Myspace. Two comparison images from Myspace are shown: (b) is a Iphone 3gs image and (c) is a Iphone 4 image after Myspace processing. Visual comparison is inconclusive. (a) and (b) happen to both be Iphone 3gs images from Myspace. Comparing several database images and unknown images (from the same source) provides a higher chance of getting a good comparison.



Another way of comparing Compression Level Analysis values is by computing correlation coefficients. Figure 20 shows the correlation coefficients of comparisons between a set of 1000 database images and an evidence file for each camera. Results were improved slightly in Figure 21 by comparing the entire set of 100 images per evidence camera to database bounds files that were created with 1000s images per camera.



**Figure 18 Visual Analysis of the CLA graphs:**  
**(a) unknown image (b) Iphone 4 (c) Blackberry 9630**



**Figure 19 Visual Analysis of the CLA graphs:**  
(a) unknown image (b) Iphone 3gs (c) Iphone 4

## Evidence

MS CLA (10 <sup>-4</sup> )	BlackBerry 8220	BlackBerry 8330	BlackBerry 9630	HTC EVO 4G	HTC Trophy	Iphone 3gs	Iphone 4	Moto Cliq	myTouch 3g
BlackBerry 8220	8.137924	1.035192	4.128476	0.160340	0.170629	0.410947	0.130122	0.387368	5.104571
BlackBerry 8330	0.802366	0.480355	0.637146	1.402276	0.447099	1.067850	0.280445	0.015096	0.575658
BlackBerry 9630	-0.520764	-1.985024	4.328719	1.195647	-0.820402	0.560466	0.398243	0.479906	3.734199
HTC EVO 4G	2.009978	0.857954	2.781525	5.272244	1.379014	2.927852	1.194785	1.736767	0.722307
HTC Trophy	1.615223	0.517807	1.348160	0.685387	0.625574	-0.544331	0.307442	-0.844984	-0.956594
Iphone 3gs	-0.862377	-0.106058	-0.308055	3.025248	0.519058	2.738466	0.175664	2.455793	1.916648
Iphone 4	0.146709	-0.487489	0.779164	1.296052	2.894473	0.553082	1.845296	-0.255366	0.556869
Moto Cliq	0.939129	-0.947985	3.068425	0.374696	0.680593	0.541077	-1.434051	0.426081	1.344976
myTouch 3g	-0.576551	-2.116025	5.637958	1.310072	1.240868	2.149378	1.463614	1.092350	6.064369

**Figure 20 Correlation Coefficient values of the evidence images compared directly to evidence images**

Database

Bounds

Evidence										
MS CLA	BlackBerry 8220	BlackBerry 8330	BlackBerry 9630	HTC EVO 4G	HTC Trophy	Iphone 3gs	Iphone 4	Moto Cliq	myTouch 3g	
BlackBerry 8220	8	38	21	68	34	40	35	47	61	
BlackBerry 8330	38	21	39	58	42	31	21	41	72	
BlackBerry 9630	35	26	12	74	32	44	23	29	63	
HTC EVO 4G	6	0	3	2	4	4	1	1	12	
HTC Trophy	80	42	71	91	38	77	27	54	95	
Iphone 3gs	21	6	24	36	36	2	3	16	29	
Iphone 4	94	83	93	99	33	92	5	40	99	
Moto Cliq	14	5	9	33	11	23	3	2	69	
myTouch 3g	21	78	7	99	82	82	87	96	6	

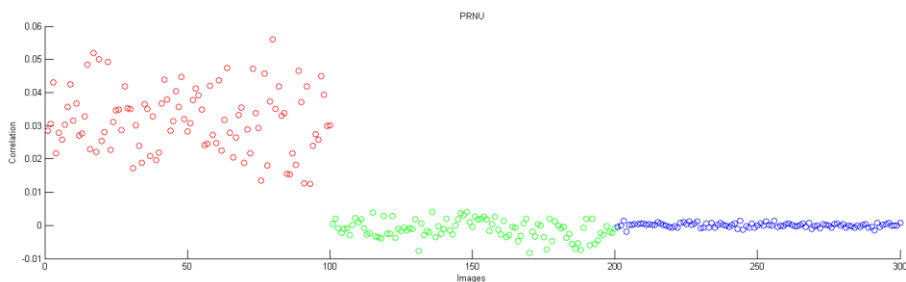
**Figure 21 Number of images in the evidence set that exceeded the database bounds**

### Specific Camera Image Attribution

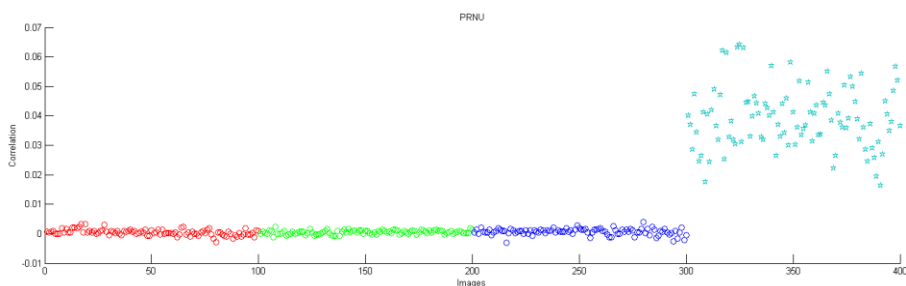
Specific Camera Image Attribution follows all the methods utilized in Camera Image Attribution with the addition of Photo Response Non Uniformity. Methods in Camera Image Attribution can be used to narrow down the possible cameras down to a single or a few camera models.

Photo Response Non Uniformity requires that a set of test images be taken with the suspect camera(s) for analysis which may not be available in some investigations. Minimizing the number of suspect cameras with the Camera Image Attribution method can make camera requests more reasonable and capturing test data less time consuming. Even though acquiring the source camera can often be difficult, PRNU is a very valuable tool because it can tell the exact camera which took the picture in question. In Figure 22, a comparison of three PRNU samples to an unknown image easily identified the matching camera as a Blackberry 8220. In Figure 23, an iPhone 4 test image is compared against four PRNU samples including two different iPhone 4 PRNU samples. The correlation difference between the alternate iPhone 4 and true iPhone 4 clearly shows how PRNU can still determine Specific Camera Image Attribution

after Social Media processing. A complete collection of PRNU comparison graphs and further analysis is included in Appendix C.



**Figure 22 Facebook PRNU Comparison: Blackberry 8220 Test Image vs. PRNU sample:**  
(red) Blackberry 8220 (green) Blackberry 8330 (blue) Blackberry 9630



**Figure 23 Google Plus PRNU Comparison: Iphone 4 Test Image vs. PRNU sample:**  
(red) HTC Trophy (green) Iphone 3gs (blue) Iphone 4 Alt (Aqua) Iphone 4

## **CHAPTER VI**

### **CONCLUSION**

In this paper, I proposed three methods of determining image attribution when different information is required. This research leveraged the immense research in image authentication but also incorporated Social Media specific fingerprints and information to overcome the processing that makes traditional image authentication techniques difficult. Three Image Attribution Methods were proposed and tested with an image test corpus. Some of the Image Attribution techniques provided high certainty while others provided less certainty. The combined techniques in each method provided sufficient certainty. However, Image Attribution much like Image Authentication will always be vulnerable to forgeries. By utilizing several methods, image forgery is much more difficult. As Social Media and image processing continues to change and evolve, this research should be built upon to deal with changing processing standards.

## **CHAPTER VII**

### **FURTHER RESEARCH**

Research into Image Authentication has exploded in the last few years. This thesis utilized image dimensions, JPEG structure, metadata information, quantization tables, supporting social media documents, compression level analysis, and photo response non-uniformity. Further analysis that could add further fingerprints include: Discrete Cosine Transform Analysis and JPEG Compression Error Level Analysis. These techniques could be applied to the Camera Model Image Attribution to further confirm the identity of a source camera model. Better Photo Response Non-Uniformity samples could be utilized using a more advanced denoising filter in the PRNU process as suggested by Amerini et Al. It is the author's hope that this system can, in the future, be enhanced with further identifiers and the results better quantified into more unified probabilistic terms.

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<<http://www.google.com/transparencyreport/userdatarequests/>>.
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## APPENDIX A

### FILE STRUCTURE ANALYSIS

<p>0 -&gt; FFD8 = JPEG Start [0]  2 -&gt; FFE1 = APP  130 -&gt; FFDB = Quantization Table  1BC -&gt; FFC0 = Baseline DCT  1CF -&gt; FFC4 = Huffman Table  373 -&gt; FFDA = Start of Scan (SOS)  10C6F4 -&gt; FFD9 = JPEG End [10C6F4]</p>	<p>0 -&gt; FFD8 = JPEG Start [0]  C0E -&gt; FFDB = Quantization Table  C53 -&gt; FFDB = Quantization Table  C98 -&gt; FFC2 = Progressive DCT  CAB -&gt; FFC4 = Huffman Table  CC8 -&gt; FFC4 = Huffman Table  CE2 -&gt; FFDA = Start of Scan (SOS)  6E0A -&gt; FFC4 = Huffman Table  6E3B -&gt; FFDA = Start of Scan (SOS)  19145 -&gt; FFC4 = Huffman Table  1916A -&gt; FFDA = Start of Scan (SOS)  19E81 -&gt; FFC4 = Huffman Table  19EA8 -&gt; FFDA = Start of Scan (SOS)  1B023 -&gt; FFC4 = Huffman Table  1B066 -&gt; FFDA = Start of Scan (SOS)  3998E -&gt; FFC4 = Huffman Table  399B6 -&gt; FFDA = Start of Scan (SOS)  5D124 -&gt; FFDA = Start of Scan (SOS)  5E732 -&gt; FFC4 = Huffman Table  5E755 -&gt; FFDA = Start of Scan (SOS)  61A59 -&gt; FFC4 = Huffman Table  61A80 -&gt; FFDA = Start of Scan (SOS)  65139 -&gt; FFC4 = Huffman Table  65162 -&gt; FFDA = Start of Scan (SOS)  A6866 -&gt; FFD9 = JPEG End [A6866]</p>
<p>0 -&gt; FFD8 = JPEG Start [0]  C14 -&gt; FFDB = Quantization Table  C59 -&gt; FFDB = Quantization Table  C9E -&gt; FFC2 = Progressive DCT  CB1 -&gt; FFC4 = Huffman Table  CCD -&gt; FFC4 = Huffman Table  CE6 -&gt; FFC4 = Huffman Table  CFE -&gt; FFDA = Start of Scan (SOS)  63AA -&gt; FFC4 = Huffman Table  63D8 -&gt; FFDA = Start of Scan (SOS)  14F4E -&gt; FFC4 = Huffman Table  14F72 -&gt; FFDA = Start of Scan (SOS)  1531C -&gt; FFC4 = Huffman Table  15343 -&gt; FFDA = Start of Scan (SOS)  159B8 -&gt; FFC4 = Huffman Table  159F9 -&gt; FFDA = Start of Scan (SOS)  299CF -&gt; FFC4 = Huffman Table  299F7 -&gt; FFDA = Start of Scan (SOS)  471CC -&gt; FFDA = Start of Scan (SOS)  487E8 -&gt; FFC4 = Huffman Table  4880A -&gt; FFDA = Start of Scan (SOS)  4AF62 -&gt; FFC4 = Huffman Table  4AF86 -&gt; FFDA = Start of Scan (SOS)  4DADC -&gt; FFC4 = Huffman Table  4DB05 -&gt; FFDA = Start of Scan (SOS)  7CE46 -&gt; FFD9 = JPEG End [7CE46]</p>	<p>0 -&gt; FFD8 = JPEG Start [0]  14 -&gt; FFE1 = APP  212 -&gt; FFD8 = JPEG Start [212]  226 -&gt; FFDB = Quantization Table  26B -&gt; FFDB = Quantization Table  2B0 -&gt; FFC0 = Baseline DCT  2C3 -&gt; FFC4 = Huffman Table  2E0 -&gt; FFC4 = Huffman Table  318 -&gt; FFC4 = Huffman Table  332 -&gt; FFC4 = Huffman Table  34E -&gt; FFDA = Start of Scan (SOS)  1668 -&gt; FFD9 = JPEG End [1669]  166A -&gt; FFE1 = APP  178E -&gt; FFDB = Quantization Table  1814 -&gt; FFC0 = Baseline DCT  1827 -&gt; FFC4 = Huffman Table  1846 -&gt; FFC4 = Huffman Table  1898 -&gt; FFC4 = Huffman Table  18B4 -&gt; FFC4 = Huffman Table  18EA -&gt; FFDA = Start of Scan (SOS)  CF45E -&gt; FFD9 = JPEG End [CF45E]</p>

**Figure 24 File Structure after social media processing**  
**(a) Blackberry 8330 Original (b) Facebook Processed (c) Myspace Processed (d) Google Plus Processed**



<p>0 -&gt; FFD8 = JPEG Start [0]  2 -&gt; FFE1 = APP  19E -&gt; FFDB = Quantization Table  224 -&gt; FFC4 = Huffman Table  3C8 -&gt; FFC0 = Baseline DCT  3DB -&gt; FFDA = Start of Scan (SOS)  8AC21 -&gt; FFD9 = JPEG End [8AC21]</p>	(a)	<p>0 -&gt; FFD8 = JPEG Start [0]  C0E -&gt; FFDB = Quantization Table  C53 -&gt; FFDB = Quantization Table  C98 -&gt; FFC2 = Progressive DCT  CAB -&gt; FFC4 = Huffman Table  CC7 -&gt; FFC4 = Huffman Table  CE1 -&gt; FFDA = Start of Scan (SOS)  7AAF -&gt; FFC4 = Huffman Table  7ADD -&gt; FFDA = Start of Scan (SOS)  E6B0 -&gt; FFC4 = Huffman Table  E6D4 -&gt; FFDA = Start of Scan (SOS)  F5EE -&gt; FFC4 = Huffman Table  F613 -&gt; FFDA = Start of Scan (SOS)  FD01 -&gt; FFC4 = Huffman Table  FD3A -&gt; FFDA = Start of Scan (SOS)  134BF -&gt; FFC4 = Huffman Table  134E8 -&gt; FFDA = Start of Scan (SOS)  29193 -&gt; FFDA = Start of Scan (SOS)  2B5C5 -&gt; FFC4 = Huffman Table  2B5E9 -&gt; FFDA = Start of Scan (SOS)  3156E -&gt; FFC4 = Huffman Table  31591 -&gt; FFDA = Start of Scan (SOS)  36886 -&gt; FFC4 = Huffman Table  368AD -&gt; FFDA = Start of Scan (SOS)  713D5 -&gt; FFD9 = JPEG End [713D5]</p>	(c)
<p>0 -&gt; FFD8 = JPEG Start [0]  C14 -&gt; FFDB = Quantization Table  C59 -&gt; FFDB = Quantization Table  C9E -&gt; FFC2 = Progressive DCT  CB1 -&gt; FFC4 = Huffman Table  CCD -&gt; FFC4 = Huffman Table  CE7 -&gt; FFC4 = Huffman Table  D01 -&gt; FFDA = Start of Scan (SOS)  7B25 -&gt; FFC4 = Huffman Table  7B52 -&gt; FFDA = Start of Scan (SOS)  EB13 -&gt; FFC4 = Huffman Table  EB38 -&gt; FFDA = Start of Scan (SOS)  FE2C -&gt; FFC4 = Huffman Table  FE51 -&gt; FFDA = Start of Scan (SOS)  10805 -&gt; FFC4 = Huffman Table  1083E -&gt; FFDA = Start of Scan (SOS)  14009 -&gt; FFC4 = Huffman Table  14032 -&gt; FFDA = Start of Scan (SOS)  2BC47 -&gt; FFDA = Start of Scan (SOS)  2E07F -&gt; FFC4 = Huffman Table  2E0A7 -&gt; FFDA = Start of Scan (SOS)  34912 -&gt; FFC4 = Huffman Table  34936 -&gt; FFDA = Start of Scan (SOS)  39FF4 -&gt; FFC4 = Huffman Table  3A01C -&gt; FFDA = Start of Scan (SOS)  73A93 -&gt; FFD9 = JPEG End [73A93]</p>	(b)	<p>0 -&gt; FFD8 = JPEG Start [0]  14 -&gt; FFE1 = APP  212 -&gt; FFD8 = JPEG Start [212]  226 -&gt; FFDB = Quantization Table  26B -&gt; FFDB = Quantization Table  2B0 -&gt; FFC0 = Baseline DCT  2C3 -&gt; FFC4 = Huffman Table  2E0 -&gt; FFC4 = Huffman Table  318 -&gt; FFC4 = Huffman Table  332 -&gt; FFC4 = Huffman Table  34E -&gt; FFDA = Start of Scan (SOS)  1668 -&gt; FFD9 = JPEG End [1669]  166A -&gt; FFE1 = APP  178E -&gt; FFDB = Quantization Table  1814 -&gt; FFC0 = Baseline DCT  1827 -&gt; FFC4 = Huffman Table  1846 -&gt; FFC4 = Huffman Table  1898 -&gt; FFC4 = Huffman Table  18B4 -&gt; FFC4 = Huffman Table  18EA -&gt; FFDA = Start of Scan (SOS)  CF45E -&gt; FFD9 = JPEG End [CF45E]</p>	(d)

Figure 25 File Structure after social media processing

(a) Blackberry 9630 Original (b) Facebook Processed (c) Myspace Processed (d) Google Plus Processed

<p>0 -&gt; FFD8 = JPEG Start [0]  2 -&gt; FFE1 = APP  2C2 -&gt; FFD8 = JPEG Start [2C2]  2C4 -&gt; FFDB = Quantization Table  34A -&gt; FFC0 = Baseline DCT  35D -&gt; FFC4 = Huffman Table  501 -&gt; FFDA = Start of Scan (SOS)  63C3 -&gt; FFD9 = JPEG End [63C4]  63C5 -&gt; FFDB = Quantization Table  644B -&gt; FFC0 = Baseline DCT  645E -&gt; FFC4 = Huffman Table  6602 -&gt; FFDA = Start of Scan (SOS)  DD412 -&gt; FFD9 = JPEG End [DD412]</p>	(a)	<p>0 -&gt; FFD8 = JPEG Start [0]  C0E -&gt; FFDB = Quantization Table  C53 -&gt; FFDB = Quantization Table  C98 -&gt; FFC2 = Progressive DCT  CAB -&gt; FFC4 = Huffman Table  CC8 -&gt; FFC4 = Huffman Table  CE2 -&gt; FFDA = Start of Scan (SOS)  69B9 -&gt; FFC4 = Huffman Table  69E2 -&gt; FFDA = Start of Scan (SOS)  984E -&gt; FFC4 = Huffman Table  9873 -&gt; FFDA = Start of Scan (SOS)  A56A -&gt; FFC4 = Huffman Table  A58F -&gt; FFDA = Start of Scan (SOS)  AEEA -&gt; FFC4 = Huffman Table  AF11 -&gt; FFDA = Start of Scan (SOS)  AFF1 -&gt; FFC4 = Huffman Table  B019 -&gt; FFDA = Start of Scan (SOS)  131BA -&gt; FFDA = Start of Scan (SOS)  14EC2 -&gt; FFC4 = Huffman Table  14EE4 -&gt; FFDA = Start of Scan (SOS)  18A0D -&gt; FFC4 = Huffman Table  18A32 -&gt; FFDA = Start of Scan (SOS)  1BD27 -&gt; FFC4 = Huffman Table  1BD4F -&gt; FFDA = Start of Scan (SOS)  37E36 -&gt; FFD9 = JPEG End [37E36]</p>	(c)
<p>0 -&gt; FFD8 = JPEG Start [0]  C14 -&gt; FFDB = Quantization Table  C59 -&gt; FFDB = Quantization Table  C9E -&gt; FFC2 = Progressive DCT  CB1 -&gt; FFC4 = Huffman Table  CCD -&gt; FFC4 = Huffman Table  CE6 -&gt; FFC4 = Huffman Table  CFF -&gt; FFDA = Start of Scan (SOS)  551D -&gt; FFC4 = Huffman Table  5544 -&gt; FFDA = Start of Scan (SOS)  6851 -&gt; FFC4 = Huffman Table  6874 -&gt; FFDA = Start of Scan (SOS)  69C1 -&gt; FFC4 = Huffman Table  69E3 -&gt; FFDA = Start of Scan (SOS)  6AFF -&gt; FFC4 = Huffman Table  6B17 -&gt; FFDA = Start of Scan (SOS)  6B26 -&gt; FFC4 = Huffman Table  6B4B -&gt; FFDA = Start of Scan (SOS)  9753 -&gt; FFDA = Start of Scan (SOS)  B450 -&gt; FFC4 = Huffman Table  B471 -&gt; FFDA = Start of Scan (SOS)  D518 -&gt; FFC4 = Huffman Table  D539 -&gt; FFDA = Start of Scan (SOS)  EFB1 -&gt; FFC4 = Huffman Table  EFDC -&gt; FFDA = Start of Scan (SOS)  1C1C3 -&gt; FFD9 = JPEG End [1C1C3]</p>	(b)	<p>0 -&gt; FFD8 = JPEG Start [0]  14 -&gt; FFE1 = APP  352 -&gt; FFD8 = JPEG Start [352]  366 -&gt; FFDB = Quantization Table  3AB -&gt; FFDB = Quantization Table  3F0 -&gt; FFC0 = Baseline DCT  403 -&gt; FFC4 = Huffman Table  421 -&gt; FFC4 = Huffman Table  462 -&gt; FFC4 = Huffman Table  47D -&gt; FFC4 = Huffman Table  4A0 -&gt; FFDA = Start of Scan (SOS)  132E -&gt; FFD9 = JPEG End [132F]  1330 -&gt; FFE1 = APP  1454 -&gt; FFDB = Quantization Table  14DA -&gt; FFC0 = Baseline DCT  14ED -&gt; FFC4 = Huffman Table  150C -&gt; FFC4 = Huffman Table  1555 -&gt; FFC4 = Huffman Table  1571 -&gt; FFC4 = Huffman Table  15A0 -&gt; FFDA = Start of Scan (SOS)  43612 -&gt; FFD9 = JPEG End [43612]</p>	(d)

Figure 26 File Structure after social media processing

(a) HTC PC36100 Original (b) Facebook Processed (c) Myspace Processed (d) Google Plus Processed

0 -> FFD8 = JPEG Start [0] 2 -> FFE1 = APP 1282 -> FFD8 = JPEG Start [1282] 1284 -> FFDB = Quantization Table 12C9 -> FFDB = Quantization Table 130E -> FFC0 = Baseline DCT 1321 -> FFC4 = Huffman Table 1342 -> FFC4 = Huffman Table 13F9 -> FFC4 = Huffman Table 141A -> FFC4 = Huffman Table 14D1 -> FFDA = Start of Scan (SOS) 4BAF -> FFD9 = JPEG End [4BB0] 4BB2 -> FFE1 = APP 55F9 -> FFDB = Quantization Table 563E -> FFDB = Quantization Table 5683 -> FFC0 = Baseline DCT 5696 -> FFC4 = Huffman Table 56B7 -> FFC4 = Huffman Table 576E -> FFC4 = Huffman Table 578F -> FFC4 = Huffman Table 5846 -> FFDA = Start of Scan (SOS) 177FE0 -> FFD9 = JPEG End [177FE0]	(a)	0 -> FFD8 = JPEG Start [0] C0E -> FFDB = Quantization Table C53 -> FFDB = Quantization Table C98 -> FFC2 = Progressive DCT CAB -> FFC4 = Huffman Table CC8 -> FFC4 = Huffman Table CE2 -> FFDA = Start of Scan (SOS) 9D53 -> FFC4 = Huffman Table 9D83 -> FFDA = Start of Scan (SOS) 1E7DC -> FFC4 = Huffman Table 1E806 -> FFDA = Start of Scan (SOS) 1FFEC -> FFC4 = Huffman Table 20014 -> FFDA = Start of Scan (SOS) 20A89 -> FFC4 = Huffman Table 20AD0 -> FFDA = Start of Scan (SOS) 3AE11 -> FFC4 = Huffman Table 3AE3A -> FFDA = Start of Scan (SOS) 65A9D -> FFDA = Start of Scan (SOS) 67EC8 -> FFC4 = Huffman Table 67EEC -> FFDA = Start of Scan (SOS) 6D08F -> FFC4 = Huffman Table 6D0B2 -> FFDA = Start of Scan (SOS) 7112A -> FFC4 = Huffman Table 71152 -> FFDA = Start of Scan (SOS) B6349 -> FFD9 = JPEG End [B6349]	(c)
0 -> FFD8 = JPEG Start [0] C14 -> FFDB = Quantization Table C59 -> FFDB = Quantization Table C9E -> FFC2 = Progressive DCT CB1 -> FFC4 = Huffman Table CCE -> FFC4 = Huffman Table CE8 -> FFC4 = Huffman Table D02 -> FFDA = Start of Scan (SOS) 8BE0 -> FFC4 = Huffman Table 8C0F -> FFDA = Start of Scan (SOS) 16B62 -> FFC4 = Huffman Table 16B89 -> FFDA = Start of Scan (SOS) 1730A -> FFC4 = Huffman Table 17332 -> FFDA = Start of Scan (SOS) 175FB -> FFC4 = Huffman Table 1763C -> FFDA = Start of Scan (SOS) 239DA -> FFC4 = Huffman Table 23A04 -> FFDA = Start of Scan (SOS) 43AFD -> FFDA = Start of Scan (SOS) 45F38 -> FFC4 = Huffman Table 45F5B -> FFDA = Start of Scan (SOS) 49E76 -> FFC4 = Huffman Table 49E98 -> FFDA = Start of Scan (SOS) 4C944 -> FFC4 = Huffman Table 4C96C -> FFDA = Start of Scan (SOS) 90884 -> FFD9 = JPEG End [90884]	(b)	0 -> FFD8 = JPEG Start [0] 14 -> FFE1 = APP 1292 -> FFD8 = JPEG Start [1292] 12A6 -> FFDB = Quantization Table 12EB -> FFDB = Quantization Table 1330 -> FFC0 = Baseline DCT 1343 -> FFC4 = Huffman Table 1361 -> FFC4 = Huffman Table 13A1 -> FFC4 = Huffman Table 13BC -> FFC4 = Huffman Table 13DC -> FFDA = Start of Scan (SOS) 2804 -> FFD9 = JPEG End [2805] 2806 -> FFE1 = APP 2A27 -> FFDB = Quantization Table 2AAD -> FFC0 = Baseline DCT 2AC0 -> FFC4 = Huffman Table 2ADF -> FFC4 = Huffman Table 2B37 -> FFC4 = Huffman Table 2B53 -> FFC4 = Huffman Table 2B8B -> FFDA = Start of Scan (SOS) D8E2D -> FFD9 = JPEG End [D8E2D]	(d)

Figure 27 File Structure after social media processing

(a) HTC Trophy Original (b) Facebook Processed (c) Myspace Processed (d) Google Plus Processed

**(a)**

0 -> FFD8 = JPEG Start [0]  
 2 -> FFE1 = APP  
 1D6 -> FFD8 = JPEG Start [1D6]  
 1D8 -> FFDB = Quantization Table  
 25E -> FFC0 = Baseline DCT  
 271 -> FFC4 = Huffman Table  
 415 -> FFDA = Start of Scan (SOS)  
 F0B -> FFD9 = JPEG End [F0C]  
 F0D -> FFDB = Quantization Table  
 F93 -> FFC0 = Baseline DCT  
 FA6 -> FFC4 = Huffman Table  
 114A -> FFDA = Start of Scan (SOS)  
 F4928 -> FFD9 = JPEG End [F4928]

**(b)**

0 -> FFD8 = JPEG Start [0]  
 C14 -> FFDB = Quantization Table  
 C59 -> FFDB = Quantization Table  
 C9E -> FFC2 = Progressive DCT  
 CB1 -> FFC4 = Huffman Table  
 CCD -> FFC4 = Huffman Table  
 CE6 -> FFC4 = Huffman Table  
 CFF -> FFDA = Start of Scan (SOS)  
 7FC5 -> FFC4 = Huffman Table  
 7FF3 -> FFDA = Start of Scan (SOS)  
 FE9A -> FFC4 = Huffman Table  
 FEC0 -> FFDA = Start of Scan (SOS)  
 1045E -> FFC4 = Huffman Table  
 10487 -> FFDA = Start of Scan (SOS)  
 10680 -> FFC4 = Huffman Table  
 106B9 -> FFDA = Start of Scan (SOS)  
 12A26 -> FFC4 = Huffman Table  
 12A4F -> FFDA = Start of Scan (SOS)  
 264E8 -> FFDA = Start of Scan (SOS)  
 2893B -> FFC4 = Huffman Table  
 2895D -> FFDA = Start of Scan (SOS)  
 2C561 -> FFC4 = Huffman Table  
 2C582 -> FFDA = Start of Scan (SOS)  
 2E3BD -> FFC4 = Huffman Table  
 2E3E5 -> FFDA = Start of Scan (SOS)  
 6163A -> FFD9 = JPEG End [6163A]

**(c)**

0 -> FFD8 = JPEG Start [0]  
 C0E -> FFDB = Quantization Table  
 C53 -> FFDB = Quantization Table  
 C98 -> FFC2 = Progressive DCT  
 CAB -> FFC4 = Huffman Table  
 CC8 -> FFC4 = Huffman Table  
 CE2 -> FFDA = Start of Scan (SOS)  
 8EAC -> FFC4 = Huffman Table  
 8ED9 -> FFDA = Start of Scan (SOS)  
 1736D -> FFC4 = Huffman Table  
 17394 -> FFDA = Start of Scan (SOS)  
 18763 -> FFC4 = Huffman Table  
 18789 -> FFDA = Start of Scan (SOS)  
 18DA9 -> FFC4 = Huffman Table  
 18DE6 -> FFDA = Start of Scan (SOS)  
 200A9 -> FFC4 = Huffman Table  
 200D2 -> FFDA = Start of Scan (SOS)  
 3D2DD -> FFDA = Start of Scan (SOS)  
 3F70E -> FFC4 = Huffman Table  
 3F732 -> FFDA = Start of Scan (SOS)  
 445C0 -> FFC4 = Huffman Table  
 445E2 -> FFDA = Start of Scan (SOS)  
 47B61 -> FFC4 = Huffman Table  
 47B89 -> FFDA = Start of Scan (SOS)  
 7A480 -> FFD9 = JPEG End [7A480]

**(d)**

0 -> FFD8 = JPEG Start [0]  
 14 -> FFE1 = APP  
 254 -> FFD8 = JPEG Start [254]  
 268 -> FFDB = Quantization Table  
 2AD -> FFDB = Quantization Table  
 2F2 -> FFC0 = Baseline DCT  
 305 -> FFC4 = Huffman Table  
 322 -> FFC4 = Huffman Table  
 35B -> FFC4 = Huffman Table  
 375 -> FFC4 = Huffman Table  
 394 -> FFDA = Start of Scan (SOS)  
 13E4 -> FFD9 = JPEG End [13E5]  
 13E6 -> FFE1 = APP  
 150A -> FFDB = Quantization Table  
 1590 -> FFC0 = Baseline DCT  
 15A3 -> FFC4 = Huffman Table  
 15C2 -> FFC4 = Huffman Table  
 1615 -> FFC4 = Huffman Table  
 1631 -> FFC4 = Huffman Table  
 1669 -> FFDA = Start of Scan (SOS)  
 8D0BD -> FFD9 = JPEG End [8D0BD]

**Figure 28 File Structure after social media processing**

**(a) Moto Cliq Original (b) Facebook Processed (c) Myspace Processed (d) Google Plus Processed**

<p>0 -&gt; FFD8 = JPEG Start [0]  2 -&gt; FFE1 = APP  29E -&gt; FFD8 = JPEG Start [29E]  2A0 -&gt; FFDB = Quantization Table  2E5 -&gt; FFDB = Quantization Table  32A -&gt; FFC0 = Baseline DCT  33D -&gt; FFC4 = Huffman Table  35E -&gt; FFC4 = Huffman Table  415 -&gt; FFC4 = Huffman Table  436 -&gt; FFC4 = Huffman Table  4ED -&gt; FFDA = Start of Scan (SOS)  2216 -&gt; FFD9 = JPEG End [2217]  221A -&gt; FFDB = Quantization Table  22A0 -&gt; FFC0 = Baseline DCT  22B3 -&gt; FFC4 = Huffman Table  2457 -&gt; FFDA = Start of Scan (SOS)  17668B -&gt; FFD9 = JPEG End [17668B]</p>	(a)	<p>0 -&gt; FFD8 = JPEG Start [0]  C0E -&gt; FFDB = Quantization Table  C53 -&gt; FFDB = Quantization Table  C98 -&gt; FFC2 = Progressive DCT  CAB -&gt; FFC4 = Huffman Table  CC8 -&gt; FFC4 = Huffman Table  CE2 -&gt; FFDA = Start of Scan (SOS)  A1D8 -&gt; FFC4 = Huffman Table  A206 -&gt; FFDA = Start of Scan (SOS)  1FC78 -&gt; FFC4 = Huffman Table  1FC9E -&gt; FFDA = Start of Scan (SOS)  20357 -&gt; FFC4 = Huffman Table  2037F -&gt; FFDA = Start of Scan (SOS)  20DBE -&gt; FFC4 = Huffman Table  20DFB -&gt; FFDA = Start of Scan (SOS)  32655 -&gt; FFC4 = Huffman Table  3267D -&gt; FFDA = Start of Scan (SOS)  593F3 -&gt; FFDA = Start of Scan (SOS)  5B825 -&gt; FFC4 = Huffman Table  5B847 -&gt; FFDA = Start of Scan (SOS)  5E2EF -&gt; FFC4 = Huffman Table  5E311 -&gt; FFDA = Start of Scan (SOS)  614AB -&gt; FFC4 = Huffman Table  614D2 -&gt; FFDA = Start of Scan (SOS)  A80D2 -&gt; FFD9 = JPEG End [A80D2]</p>	(c)
<p>0 -&gt; FFD8 = JPEG Start [0]  C14 -&gt; FFDB = Quantization Table  C59 -&gt; FFDB = Quantization Table  C9E -&gt; FFC2 = Progressive DCT  CB1 -&gt; FFC4 = Huffman Table  CCE -&gt; FFC4 = Huffman Table  CE8 -&gt; FFC4 = Huffman Table  D02 -&gt; FFDA = Start of Scan (SOS)  AC4A -&gt; FFC4 = Huffman Table  AC76 -&gt; FFDA = Start of Scan (SOS)  224BD -&gt; FFC4 = Huffman Table  224E5 -&gt; FFDA = Start of Scan (SOS)  22D75 -&gt; FFC4 = Huffman Table  22D9F -&gt; FFDA = Start of Scan (SOS)  23A7A -&gt; FFC4 = Huffman Table  23AB8 -&gt; FFDA = Start of Scan (SOS)  39A4F -&gt; FFC4 = Huffman Table  39A77 -&gt; FFDA = Start of Scan (SOS)  64081 -&gt; FFDA = Start of Scan (SOS)  66492 -&gt; FFC4 = Huffman Table  664B6 -&gt; FFDA = Start of Scan (SOS)  69525 -&gt; FFC4 = Huffman Table  6954A -&gt; FFDA = Start of Scan (SOS)  6CE9C -&gt; FFC4 = Huffman Table  6CEC4 -&gt; FFDA = Start of Scan (SOS)  B1C48 -&gt; FFD9 = JPEG End [B1C48]</p>	(b)	<p>0 -&gt; FFD8 = JPEG Start [0]  14 -&gt; FFE1 = APP  310 -&gt; FFD8 = JPEG Start [310]  324 -&gt; FFDB = Quantization Table  369 -&gt; FFDB = Quantization Table  3AE -&gt; FFC0 = Baseline DCT  3C1 -&gt; FFC4 = Huffman Table  3DD -&gt; FFC4 = Huffman Table  41A -&gt; FFC4 = Huffman Table  435 -&gt; FFC4 = Huffman Table  456 -&gt; FFDA = Start of Scan (SOS)  18A6 -&gt; FFD9 = JPEG End [18A7]  18A8 -&gt; FFE1 = APP  19CC -&gt; FFDB = Quantization Table  1A52 -&gt; FFC0 = Baseline DCT  1A65 -&gt; FFC4 = Huffman Table  1A84 -&gt; FFC4 = Huffman Table  1AD2 -&gt; FFC4 = Huffman Table  1AEE -&gt; FFC4 = Huffman Table  1B23 -&gt; FFDA = Start of Scan (SOS)  104F8D -&gt; FFD9 = JPEG End [104F8D]</p>	(d)

Figure 29 File Structure after social media processing

(a) Iphone 3gs Original (b) Facebook Processed (c) Myspace Processed (d) Google Plus Processed

<p>0 -&gt; FFD8 = JPEG Start [0]  2 -&gt; FFE1 = APP  380 -&gt; FFD8 = JPEG Start [380]  382 -&gt; FFDB = Quantization Table  3C7 -&gt; FFDB = Quantization Table  40C -&gt; FFC0 = Baseline DCT  41F -&gt; FFC4 = Huffman Table  440 -&gt; FFC4 = Huffman Table  4F7 -&gt; FFC4 = Huffman Table  518 -&gt; FFC4 = Huffman Table  5CF -&gt; FFDA = Start of Scan (SOS)  1EEC -&gt; FFD9 = JPEG End [1EED]  2002 -&gt; FFDB = Quantization Table  2088 -&gt; FFC0 = Baseline DCT  209B -&gt; FFC4 = Huffman Table  223F -&gt; FFDA = Start of Scan (SOS)  2166C1 -&gt; FFD9 = JPEG End [2166C1]</p>	(a)	<p>0 -&gt; FFD8 = JPEG Start [0]  C0E -&gt; FFDB = Quantization Table  C53 -&gt; FFDB = Quantization Table  C98 -&gt; FFC2 = Progressive DCT  CAB -&gt; FFC4 = Huffman Table  CC9 -&gt; FFC4 = Huffman Table  CE2 -&gt; FFDA = Start of Scan (SOS)  9366 -&gt; FFC4 = Huffman Table  9394 -&gt; FFDA = Start of Scan (SOS)  1B557 -&gt; FFC4 = Huffman Table  1B57B -&gt; FFDA = Start of Scan (SOS)  1B8B1 -&gt; FFC4 = Huffman Table  1B8D7 -&gt; FFDA = Start of Scan (SOS)  1BB83 -&gt; FFC4 = Huffman Table  1BBC2 -&gt; FFDA = Start of Scan (SOS)  2A18B -&gt; FFC4 = Huffman Table  2A1B4 -&gt; FFDA = Start of Scan (SOS)  52480 -&gt; FFDA = Start of Scan (SOS)  548AD -&gt; FFC4 = Huffman Table  548CF -&gt; FFDA = Start of Scan (SOS)  56854 -&gt; FFC4 = Huffman Table  56877 -&gt; FFDA = Start of Scan (SOS)  58209 -&gt; FFC4 = Huffman Table  58232 -&gt; FFDA = Start of Scan (SOS)  9FB7A -&gt; FFD9 = JPEG End [9FB7A]</p>	(c)
<p>0 -&gt; FFD8 = JPEG Start [0]  C14 -&gt; FFDB = Quantization Table  C59 -&gt; FFDB = Quantization Table  C9E -&gt; FFC2 = Progressive DCT  CB1 -&gt; FFC4 = Huffman Table  CCE -&gt; FFC4 = Huffman Table  CE7 -&gt; FFC4 = Huffman Table  D00 -&gt; FFDA = Start of Scan (SOS)  7FE9 -&gt; FFC4 = Huffman Table  8017 -&gt; FFDA = Start of Scan (SOS)  122A5 -&gt; FFC4 = Huffman Table  122C8 -&gt; FFDA = Start of Scan (SOS)  12347 -&gt; FFC4 = Huffman Table  1236B -&gt; FFDA = Start of Scan (SOS)  12429 -&gt; FFC4 = Huffman Table  12462 -&gt; FFDA = Start of Scan (SOS)  15EA7 -&gt; FFC4 = Huffman Table  15ED1 -&gt; FFDA = Start of Scan (SOS)  310A4 -&gt; FFDA = Start of Scan (SOS)  334B3 -&gt; FFC4 = Huffman Table  334D6 -&gt; FFDA = Start of Scan (SOS)  343C6 -&gt; FFC4 = Huffman Table  343E9 -&gt; FFDA = Start of Scan (SOS)  34F51 -&gt; FFC4 = Huffman Table  34F7A -&gt; FFDA = Start of Scan (SOS)  72120 -&gt; FFD9 = JPEG End [72120]</p>	(b)	<p>0 -&gt; FFD8 = JPEG Start [0]  14 -&gt; FFE1 = APP  3FE -&gt; FFD8 = JPEG Start [3FE]  412 -&gt; FFDB = Quantization Table  457 -&gt; FFDB = Quantization Table  49C -&gt; FFC0 = Baseline DCT  4AF -&gt; FFC4 = Huffman Table  4CC -&gt; FFC4 = Huffman Table  50B -&gt; FFC4 = Huffman Table  525 -&gt; FFC4 = Huffman Table  546 -&gt; FFDA = Start of Scan (SOS)  166F -&gt; FFD9 = JPEG End [1670]  1672 -&gt; FFE1 = APP  1796 -&gt; FFDB = Quantization Table  181C -&gt; FFC0 = Baseline DCT  182F -&gt; FFC4 = Huffman Table  184E -&gt; FFC4 = Huffman Table  18A3 -&gt; FFC4 = Huffman Table  18BE -&gt; FFC4 = Huffman Table  18EA -&gt; FFDA = Start of Scan (SOS)  B1C5E -&gt; FFD9 = JPEG End [B1C5E]</p>	(d)

Figure 30 File Structure after social media processing

(a) Iphone 4 Original (b) Facebook Processed (c) Myspace Processed (d) Google Plus Processed

<p>0 -&gt; FFD8 = JPEG Start [0]  2 -&gt; FFE1 = APP  21E -&gt; FFD8 = JPEG Start [21E]  220 -&gt; FFDB = Quantization Table  2A6 -&gt; FFC0 = Baseline DCT  2B9 -&gt; FFC4 = Huffman Table  45D -&gt; FFDA = Start of Scan (SOS)  30BF -&gt; FFD9 = JPEG End [30C0]  30C1 -&gt; FFDB = Quantization Table  3147 -&gt; FFC0 = Baseline DCT  315A -&gt; FFC4 = Huffman Table  32FE -&gt; FFDA = Start of Scan (SOS)  B5B92 -&gt; FFD9 = JPEG End [B5B92]</p>	(a)	<p>0 -&gt; FFD8 = JPEG Start [0]  C0E -&gt; FFDB = Quantization Table  C53 -&gt; FFDB = Quantization Table  C98 -&gt; FFC2 = Progressive DCT  CAB -&gt; FFC4 = Huffman Table  CC8 -&gt; FFC4 = Huffman Table  CE2 -&gt; FFDA = Start of Scan (SOS)  9C7B -&gt; FFC4 = Huffman Table  9CA5 -&gt; FFDA = Start of Scan (SOS)  1C5CF -&gt; FFC4 = Huffman Table  1C5F4 -&gt; FFDA = Start of Scan (SOS)  1D763 -&gt; FFC4 = Huffman Table  1D788 -&gt; FFDA = Start of Scan (SOS)  1EB6D -&gt; FFC4 = Huffman Table  1EB9F -&gt; FFDA = Start of Scan (SOS)  2805A -&gt; FFC4 = Huffman Table  28082 -&gt; FFDA = Start of Scan (SOS)  463B3 -&gt; FFDA = Start of Scan (SOS)  487E1 -&gt; FFC4 = Huffman Table  48806 -&gt; FFDA = Start of Scan (SOS)  4EB9E -&gt; FFC4 = Huffman Table  4EBC1 -&gt; FFDA = Start of Scan (SOS)  54F53 -&gt; FFC4 = Huffman Table  54F7A -&gt; FFDA = Start of Scan (SOS)  9181D -&gt; FFD9 = JPEG End [9181D]</p>	(c)
<p>0 -&gt; FFD8 = JPEG Start [0]  14 -&gt; FFE1 = APP  2BC -&gt; FFD8 = JPEG Start [2BC]  2D0 -&gt; FFDB = Quantization Table  315 -&gt; FFDB = Quantization Table  35A -&gt; FFC0 = Baseline DCT  36D -&gt; FFC4 = Huffman Table  38A -&gt; FFC4 = Huffman Table  3C3 -&gt; FFC4 = Huffman Table  3DE -&gt; FFC4 = Huffman Table  3FE -&gt; FFDA = Start of Scan (SOS)  137B -&gt; FFD9 = JPEG End [137C]  137E -&gt; FFE1 = APP  14A2 -&gt; FFDB = Quantization Table  1528 -&gt; FFC0 = Baseline DCT  153B -&gt; FFC4 = Huffman Table  1559 -&gt; FFC4 = Huffman Table  15A2 -&gt; FFC4 = Huffman Table  15BE -&gt; FFC4 = Huffman Table  15FA -&gt; FFDA = Start of Scan (SOS)  93B6E -&gt; FFD9 = JPEG End [93B6E]</p>	(b)	<p>0 -&gt; FFD8 = JPEG Start [0]  C14 -&gt; FFDB = Quantization Table  C59 -&gt; FFDB = Quantization Table  C9E -&gt; FFC2 = Progressive DCT  CB1 -&gt; FFC4 = Huffman Table  CCD -&gt; FFC4 = Huffman Table  CE7 -&gt; FFC4 = Huffman Table  D01 -&gt; FFDA = Start of Scan (SOS)  8C7C -&gt; FFC4 = Huffman Table  8CA5 -&gt; FFDA = Start of Scan (SOS)  15469 -&gt; FFC4 = Huffman Table  1548E -&gt; FFDA = Start of Scan (SOS)  15AF6 -&gt; FFC4 = Huffman Table  15B1A -&gt; FFDA = Start of Scan (SOS)  16334 -&gt; FFC4 = Huffman Table  1635E -&gt; FFDA = Start of Scan (SOS)  19516 -&gt; FFC4 = Huffman Table  1953F -&gt; FFDA = Start of Scan (SOS)  31F7F -&gt; FFDA = Start of Scan (SOS)  3439D -&gt; FFC4 = Huffman Table  343C0 -&gt; FFDA = Start of Scan (SOS)  36FB8 -&gt; FFC4 = Huffman Table  36FDA -&gt; FFDA = Start of Scan (SOS)  39CCD -&gt; FFC4 = Huffman Table  39CF5 -&gt; FFDA = Start of Scan (SOS)  60650 -&gt; FFD9 = JPEG End [60650]</p>	(d)
<p>0 -&gt; FFD8 = JPEG Start [0]  14 -&gt; FFE1 = APP  230 -&gt; FFD8 = JPEG Start [230]  232 -&gt; FFDB = Quantization Table  2B8 -&gt; FFC0 = Baseline DCT  2CB -&gt; FFC4 = Huffman Table  46F -&gt; FFDA = Start of Scan (SOS)  30D1 -&gt; FFD9 = JPEG End [30D2]  30D3 -&gt; FFDB = Quantization Table  3118 -&gt; FFDB = Quantization Table  315D -&gt; FFC0 = Baseline DCT  3170 -&gt; FFC4 = Huffman Table  318E -&gt; FFC4 = Huffman Table  31D1 -&gt; FFC4 = Huffman Table  31ED -&gt; FFC4 = Huffman Table  321D -&gt; FFDA = Start of Scan (SOS)  51768 -&gt; FFD9 = JPEG End [51768]</p>	(e)		

Figure 31 File Structure after social media processing

(a) myTouch Original (b) Facebook Processed (c) Myspace Processed (d) Google Plus Processed  
(e) Tumblr Processed

**APPENDIX B**  
**FACEBOOK EXTRACTED METADATA INFORMATION**

**BlackBerry8220\_SN2584B9F8 HQ 2/10**



Date Taken: April 19, 2011 at 6:29 pm  
Orientation: 1  
Camera Model: BlackBerry 8220  
Exposure: 0/1

June 3, 2013 at 8:55 am

**Blackberry8330\_SN3042C00D HQ 6/10**



Date Taken: September 5, 2010 at 2:02  
pm  
Orientation: 1  
Camera Model: BlackBerry 8330

June 8, 2013 at 10:45 am



**Blackberry9630\_SN30E6CC37 HQ 10/10**

Date Taken: June 2, 2013 at 8:30 am  
Orientation: 1  
Camera Model: BlackBerry 9630  
Exposure: 0/1

June 2, 2013 at 10:16 pm

**HTCPC36100\_SNHT0CVHL05640 HQ 3/10**

Date Taken: May 18, 2013 at 10:51 am  
Latitude: 34.1277583333  
Longitude: -118.141155556  
Camera Model: PC36100  
ISO Speed: 114  
Focal Length: 457/100

June 8, 2013 at 7:11 pm

**HtcTrophy\_SNHT16JM600679 HQ 1/10**

Date Taken: April 27, 2013 at 6:19 am

Orientation: 1

Camera Model: mwp6985

ISO Speed: 100

May 31, 2013 at 7:37 pm

**MotorolaCliq\_SNJ116NJ376L HQ 2/10**

Date Taken: May 24, 2013 at 8:08 am

Camera Model: MB200

June 1, 2013 at 12:07 pm

**mytouch3g\_SNHT05SPB00016 HQ 1/10**

Date Taken: October 4, 2012 at 12:12  
am  
Latitude: 34.1430638889  
Longitude: -118.126144444  
Camera Model: T-Mobile myTouch 3G  
Focal Length: 372/100

February 14, 2013 at 12:34 am

**Iphone3gs\_SN87127NTJEDG HQ 2/10**

Date Taken: November 3, 2012 at 8:31  
am  
Orientation: 1  
Camera Model: iPhone 3GS  
Exposure: 1/1805  
F-Stop: 14/5  
ISO Speed: 64  
Focal Length: 77/20

February 12, 2013 at 5:29 am



**Iphone4\_SN86025XUGA4S HQ Part 1/10**

Date Taken: July 23, 2012 at 7:17 am  
Latitude: 39.7323333333  
Longitude: -104.961  
Orientation: 1  
Camera Model: iPhone 4  
Exposure: 1/256  
F-Stop: 14/5  
ISO Speed: 80  
Focal Length: 77/20

February 10, 2013 at 6:02 pm

## APPENDIX C

### PRNU COMPARISON GRAPHS

The PRNU comparison graphs are organized by test image source. Each graph shows several PRNU samples on the X axis. Incorrect comparisons are represented by color circles (e.g. BB Pearl Flip PRNU Sample vs. iPhone 4 test image). Correct comparisons are represented by black non-circle symbols (e.g. BB Pearl Flip PRNU Sample vs. BB Pearl Flip test image). Since no test images were included to compare against the Alternate Iphone 4 image, Iphone 4 Alt PRNU sample vs. Iphone 4 test image was used for the correct comparison.

These graphs illustrate several properties of the test images and the social media processing including the effect of social media processing on PRNU, the effect of camera sources on PRNU, and the variation between various social media processing.

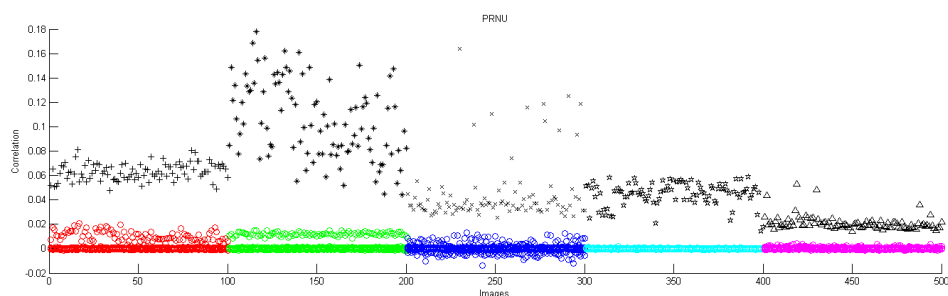
The effect of social media processing on PRNU can be seen by comparing the original test image results against social media test image results. There are higher correlations between PRNU samples and the original test images than social media processed test images. This is to be expected because of the social media processing. However, the correlations between PRNU samples and social media processed test images is still high enough to differentiate positive PRNU matches.

The effect of camera sources on PRNU can be seen by comparing the PRNU sample correlations again one another within the same test image sets. Two different properties represent themselves, overall correlation and correlation variance. The HTC Trophy has a relatively low overall correlation while the Blackberry Pearl Flip has a relatively high overall correlation. The HTC Trophy has a relatively low variance in correlation while the Blackberry Curve has a relatively high variance in correlation.

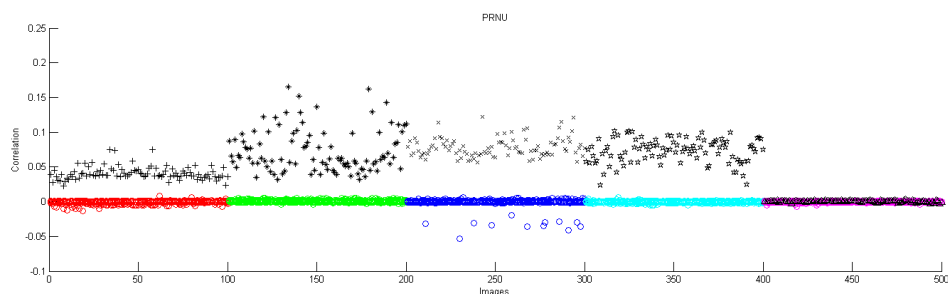
The variation between various social media processing can be seen by comparing the various social media test image results against one another. It is clear that original

test images provide more correlation than any of the social media processed test images. However, the fact that each set of social media processed images provides different levels of correlation shows that each website is applying different processing to the images.

### Original Test Images

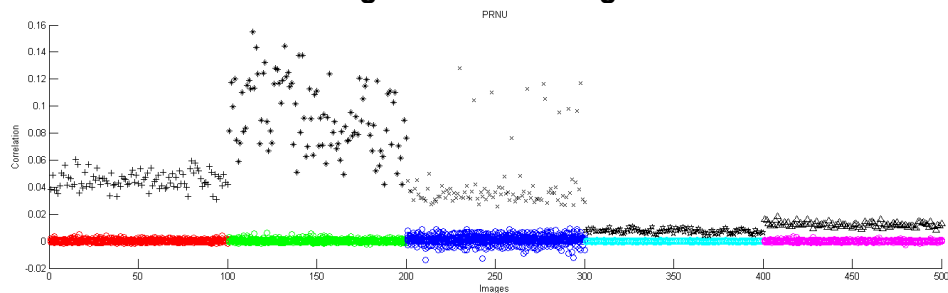


**Figure 32 PRNU Samples (Left to Right): BB Pearl Flip, BB Curve, BB Tour, HTC EVO 4g, and HTC Trophy**

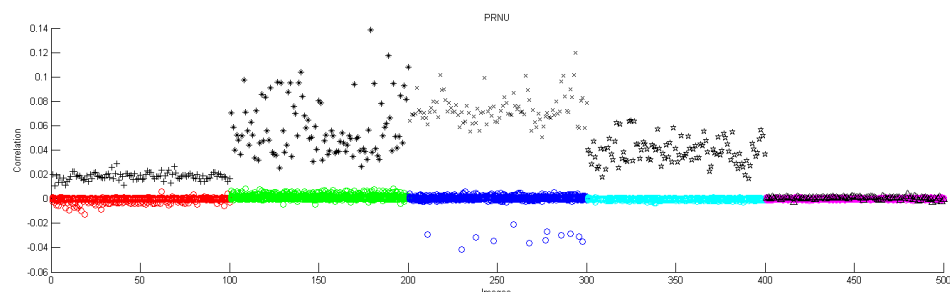


**Figure 33 PRNU Samples (Left to Right): Moto Cliq, Mytouch 3g, Iphone 3gs, Iphone 4, Iphone 4 Alt**

### Google Plus Test Images

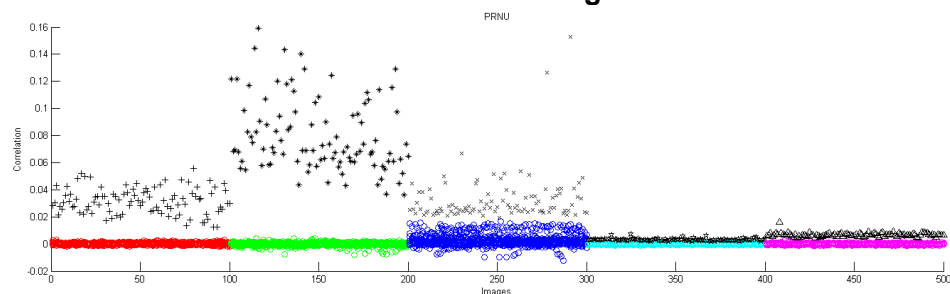


**Figure 34 PRNU Samples (Left to Right): BB Pearl Flip, BB Curve, BB Tour, HTC EVO 4g, and HTC Trophy**

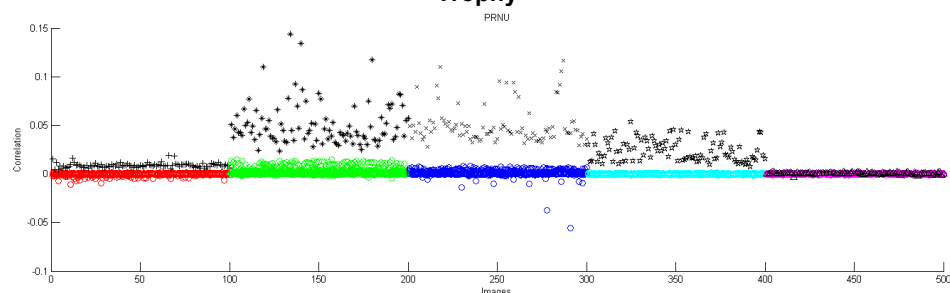


**Figure 35 PRNU Samples (Left to Right): Moto Cliq, Mytouch 3g, Iphone 3gs, Iphone 4, Iphone 4 Alt**

### Facebook Test Images

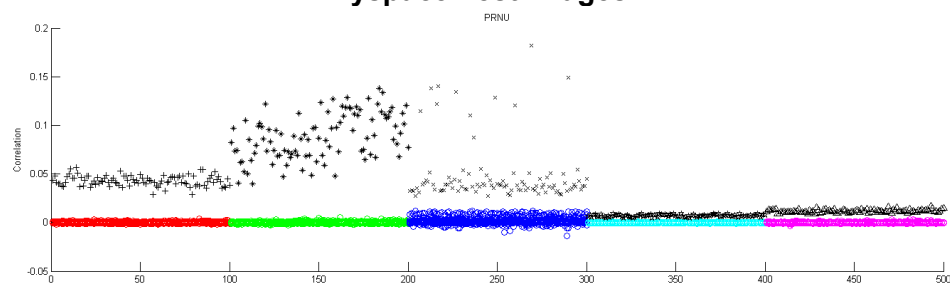


**Figure 36 PRNU Samples (Left to Right): BB Pearl Flip, BB Curve, BB Tour, HTC EVO 4g, and HTC Trophy**

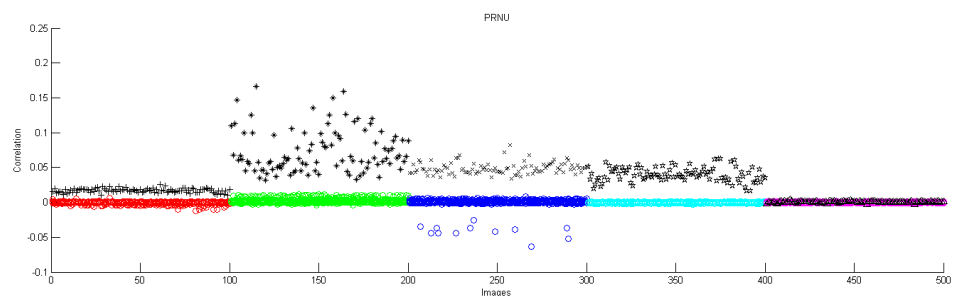


**Figure 37 PRNU Samples (Left to Right): Moto Cliq, Mytouch 3g, Iphone 3gs, Iphone 4, Iphone 4 Alt**

### Myspace Test Images



**Figure 38 PRNU Samples (Left to Right): BB Pearl Flip, BB Curve, BB Tour, HTC EVO 4g, and HTC Trophy**



**Figure 39 PRNU Samples (Left to Right): Moto Cliq, Mytouch 3g, Iphone 3gs, Iphone 4, Iphone 4 Alt**