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Source camera identification using Photo Response Non-Uniformity on WhatsApp

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ABSTRACT

The Photo Response Non-Uniformity pattern can be a method for identification for an individual camera and is often present in digital footage. Therefore, the PRNU-pattern is also called the fingerprint of the camera. This pattern can be extracted and used to identify the source camera with a high likelihood ratio. This can be useful in cases such as child abuse or child pornography. In this research a 2nd order (FSTV) based method is used to extract the PRNU-patterns from videos of ten different mobile phone cameras. By calculating the Peak to Correlation Energy the PRNU-patterns of the natural videos are compared to the PRNU-patterns of the reference flat field videos of each camera to identify the source camera. This has been done for the original videos and the transmitted videos by WhatsApp for Android and IOS to determine if source camera identification by using PRNU is possible when videos are transmitted by WhatsApp. Also the PRNU-patterns of the natural videos are compared to each other to determine the possibility to find out if videos originate from the same source. With most cameras tested the method provides a high likelihood ratio, however for each case a validation of the method is necessary with reference cameras of the same model and type if used in casework. With videos transmitted by the IOS version of Whatsapp the source camera identification was not possible anymore.

Introduction

A Swedish woman was being sexual abused for hours by three armed men. The abuse was broadcasted on Facebook Live and was being watched by almost two hundred people. At first the viewers thought it was a joke but later on one of the viewers called the police. The police arrested the three abusers what also was shown on the live stream (Daileymail, 2017). Recently crime-related footage is more common broadcasted live.

When digital footage is crime-related it can be useful to identify the source camera. In the above example the suspects were caught in the act. But when for example a suspect denies that footage of child pornography, which was found on his computer, is manufactured by him, the only charge against him could be the procession of child pornography. When the camera of the suspect can be identified with a high likelihood ratio as the source camera of the video, the suspect can also be charged for manufacture of child pornography.

To identify the source of the digital footage the Photo Response Non-Uniformity (PRNU) pattern can be extracted from the footage and needs to be compared with the PRNU-pattern of the disputed camera. The PRNU-pattern is originating from the camera sensor and therefor always present in footage taken with that camera. The PRNU-pattern is often unique for a specific camera and therefore also called the fingerprint of a camera (Scheelen and van der Lelie, 2012) At the Netherlands Forensic Institute validation of PRNU in casework is conducted by using a same model and type camera to determine how identifying the pattern is (Nederlands Forensisch Instituut, 2010; Houten and Geradts, 2009).

With the popularity of social media a lot of digital footage is being uploaded with these social media. To relieve the network and increase the uploading or sending speed, social media often compresses the digital footage. Due to lossy compression the quality of the footage will drop what will affect the PRNU-pattern. Therefore research is needed to see if it is still possible to link a video to his source when it was uploaded on social media. In this paper we will take a look at WhatsApp. The main goal is to determine if it is still possible to identify the source of videos that are transmitted by WhatsApp. Also the possibility to determine if videos originate

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from the same source after they are transmitted by WhatsApp will be investigated.

Material and methods

Cameras

In this research videos of 10 different cameras are used. Most of the videos have a resolution of 1920 × 1080 pixels. Only the videos of the Samsung Galaxy Grand Prime are taken with a resolution of 1280 × 720 pixels. The used cameras are shown in Table 1.

For each camera three videos are used. Two natural videos (one from an outside situation and one from an inside situation) and one reference flat field video from a grey surface. All videos were taken with the rear camera in portrait mode.

PRNUCompare 2.2

To extract and compare the PRNU-patterns the software PRNUCompare version 2.2 is used. This software is developed by the Netherlands Forensic Institute and is used for source camera identification (Nederlands Forensisch instituut, 2010). Four different filters can be chosen to extract the PRNU-pattern: 4th order extraction filter, wavelet (daubechies), wavelet (coiflet) and the 2nd order (FSTV) extraction filter. In this research the 2nd order (FSTV) extraction filter is used, since it provides better results for video (Brouwers and Mousa, 2017) compared to the other methods. The “frame averaging” is another parameter that can be set before extracting the PRNU-pattern.

Original videos

To determine if it is still possible to identify the source camera of a video after being transmitted by WhatsApp 2.17.79 (Android) and 2.17.20 (IOS), we first need to know if it is possible to identify the source camera of the original videos of the investigated cameras. Therefore the PRNU-patterns of the two natural videos and the flat field video of each camera are extracted. The comparison between the two natural videos of camera A and the flat field video of the same camera A delivers the PCE of the two matches. The comparison between the two natural videos of camera A and the other flat field videos not from camera A will deliver the PCE of the multiple mismatches. Only the highest mismatch will be shown in the results.

After the source camera identification the possibility to determine if videos originate from the same source before they are transmitted by WhatsApp 2.17.79 (Android) and 2.17.20 (IOS) is investigated. The PRNU-patterns of all the original natural indoor videos 1 (NA1) are compared with all the original outdoor natural videos 2 (NA2). The comparison between the original natural video 1 (NA1) from a camera and the original natural video 2 (NA2) from the same camera will deliver the PCE of the match for each camera. The comparison of the original natural video 1 from a camera and the original natural videos 2 of the other cameras will deliver the PCE of the multiple mismatches. Only the highest mismatch will be shown in the results.

Of the used cameras it is determined that the PRNU is individualizing for the individual camera of brand and model, since we have reference images of same brand and model and different cameras.

WhatsApp

Compression WhatsApp

In this research two different versions of WhatsApp are used: “WhatsApp version 2.17.79 for android and WhatsApp version 2.17.20 for IOS”. The following methodology will be executed for both WhatsApp versions. At first we will take a look at the influence of the compression on the videos by sending them with WhatsApp. This will be done by sending three videos from different cameras with different resolution, extension and frame rate. The natural videos 1 (NA 1) from the Samsung galaxy grand prime, Microsoft Lumia 950 and the Apple IPhone 6 are used. To exclude the influence of the transmitting method, the videos are transmitted in all the different ways that are possible. In Table 2 below, the different methods of sending are shown.

The videos will be transmitted using the mobile phones and WhatsApp versions showed in Table 3 below.

Also the influence of the WhatsApp version of the mobile phone that receive and forward the videos will be investigated. Therefore every video is transmitted as following:

- IOS to IOS
- IOS to Android
- Android to Android
- Android to IOS

Every action will be executed in three fold to exclude the variability within one method of sending.

After the research on the compression, all the videos are being transmitted using the sending method that delivers different compression. If resolution changes the original flat field videos will

Table 2
Methods to transmit and forward a video with WhatsApp.

Transmit	Share from save location with WhatsApp
	Add a file to the chat with WhatsApp
Forward	Share from save location with WhatsApp
	Add a file to the chat with WhatsApp
	Share the received video with WhatsApp (only possible for WhatsApp 2.17.79 for Android)
	Forward the received video with WhatsApp

Table 1
Used cameras.

Camera	Model	Resolution	Frame rate (FPS)	Extension
01	Samsung Galaxy S5 Active	1920 × 1080	29	MP4
02	Samsung Galaxy Grand Prime	1280 × 720	29	MP4
03	Samsung Galaxy S6 edge	1920 × 1080	29	MP4
04	Huawei P8 lite	1920 × 1080	29	MP4
05	Huawei G8	1920 × 1080	29	MP4
06	Microsoft Lumia 950	1920 × 1080	30	MP4
07	HTC One A9	1920 × 1080	30	MP4
08	Sony Xperia Z5 Premium	1920 × 1080	29	MP4
09	LG G4	1920 × 1080	30	MP4
10	Apple IPhone 6	1920 × 1080	29	MOV

Table 3
The mobile phones and WhatsApp versions used to transmit and receive the videos.

Phone	WhatsApp version
Samsung Galaxy S5	2.17.79
Sony Xperia Z3	2.17.79
Apple IPhone 6 plus	2.17.20
Apple IPhone 7	2.17.20

also be re-encoded using FFmpeg to get them in the same resolution as the transmitted natural videos.

Extraction and comparison

After the videos are transmitted by WhatsApp, the PRNU-patterns will be extracted and compared. There will be two comparisons. The first comparison is between the PRNU-patterns of the transmitted natural videos (NA1 and NA2) and the original flat field videos with the same resolution. The second comparison is between the transmitted natural videos (NA1 and NA2) and the transmitted flat field videos. This will be done per sending method where the compression differs. As equal to the method of the camera identification of the original videos, the comparison between the two natural videos of camera A and the flat field video of the same camera A delivers the PCE of the two matches. The comparison between the two natural videos of camera A and the other flat field videos not from camera A will deliver the PCE of the multiple mismatches. Only the highest mismatch will be shown in the results.

To determine if it is still possible to find out if videos originate from the same source after they are transmitted by WhatsApp 2.17.79 (Android) and 2.17.20 (IOS), The PRNU-patterns of all the transmitted natural videos 1 (NA1) are compared with all the transmitted natural videos 2 (NA2). The comparison between the transmitted natural video 1 (NA1) from a camera and the transmitted natural video 2 (NA2) from the same camera will deliver the PCE of the match for each camera. The comparison of the transmitted natural video 1 from a camera and the transmitted natural videos 2 of the other cameras will deliver the PCE of the multiple mismatches. Only the highest mismatch will be shown in the results.

Theory

Photo Response Non-Uniformity

In digital footage different kinds of noise, like dark current, reset noise, circuit noise and PRNU, are present. PRNU is caused by the imperfection of the camera sensor created during the manufacturing process. Not every pixel of the sensor is identical and will therefore respond different to the same amount of light. This is called the non-uniformity of pixels. When the camera sensor for example will be illuminated equal, not all pixels will measure the same amount of light. This is caused by the difference of the sensitivity of pixels to light. Over the sensor surface this creates a pixel non-uniformity pattern which is called the PRNU-pattern. Because the PRNU-pattern originates from the camera sensor, the pattern will be present in all footage taken with this camera sensor. The PRNU-pattern is unique for a specific camera and therefore also called the fingerprint of a camera (Houten and Geradts, 2009; Alles et al., 2007; Brouwers and Mousa, 2017; Lukas et al., 2005).

To determine if a video is captured with a specific camera, the PRNU-pattern from the disputed video and the disputed camera is needed. Using software the PRNU-patterns can be extracted from the videos. The first step of the extraction is to average groups of individual frames of the video. A parameter, the frame averaging rate, can be set to determine how many frames per group will be averaged. For example we take a video with thousand frames that will be averaged with a frame averaging rate of ten. Per ten frames an average will be calculated that delivers hundred averaged frames in total. The second step is to extract the noise per averaged frame. This can be done by several integrated filters in the PRNU-Compare program. Research has shown that better results were obtained with the 2nd order (FSTV) filter (Brouwers and Mousa, 2017). With this filter the noise will be removed from the footage. By subtracting the averaged frame without the noise from the averaged frame with the noise, the noise pattern will be obtained. Than as third step the noise patterns from all the averaged frames will be averaged. With this step noise that is not present in every frame, like the PRNU-pattern is, will be restrained and the PRNU-pattern becomes clearer. Due electronical imperfection some rows and columns of pixels can be systematically brighter or darker. This noise can be removed with step four by using a zero mean filter (Goljan, 2008). The last step in the extraction method is to remove artifacts created due compression. Groups of pixels, that share information to reduce data size, creates a pattern over the surface of the footage. To remove this pattern a Wiener filter is used. Finally the PNRU-pattern is as clear as possible obtained (Goljan, 2008).

To obtain the PRNU-pattern from the disputed camera, a reference video is needed. These reference videos are called flat field videos. A flat field video is taken by moving the camera over a grey surface. By moving the camera over a grey surface the camera sensor is illuminated as equal as possible and also no objects will be present in the video. This causes the PRNU-pattern to be as clear as possible.

When the PNRU-patterns from the disputed video and the disputed camera are extracted, the two PRNU-patterns can be compared. This can also be done using PRNUCompare. PRNU-Compare compares the patterns and calculates the Peak to Correlation Energy (PCE).

Related work

For some cameras it is possible to identify the source camera from videos that were uploaded to YouTube (Brouwers and Mousa, 2017; Scheelen and van der Lelie, 2012). The PRNU-patterns of uploaded videos were compared to the PRNU-patterns of flat field videos that were not uploaded. When the flat field videos at first were uploaded to YouTube, it was no longer possible to match the source camera to their videos. Therefore flat field videos were off-line compressed to the same resolution using FFmpeg (Brouwers and Mousa, 2017). These results are in line with a non-public investigation from the NFI, that concluded that is was not possible to identify the source camera of videos when they are uploaded to YouTube (Cents, 2015). The flat field videos however were uploaded to YouTube what explains the negative results. The different filters built in PRNUCompare were also investigated by Brouwers and Mousa. This research showed that better results were made using the 2nd order (FSTV) extraction method (Brouwers and Mousa, 2017).

Results

Original videos

To determine if it is still possible to identify the source camera of the two original videos of each camera, the PRNU-patterns of these natural videos are compared with the flat field videos of each camera. In Fig. 1 the results of this comparison are shown for the cameras with lower PCE's and in Fig. 2 the results for the camera's

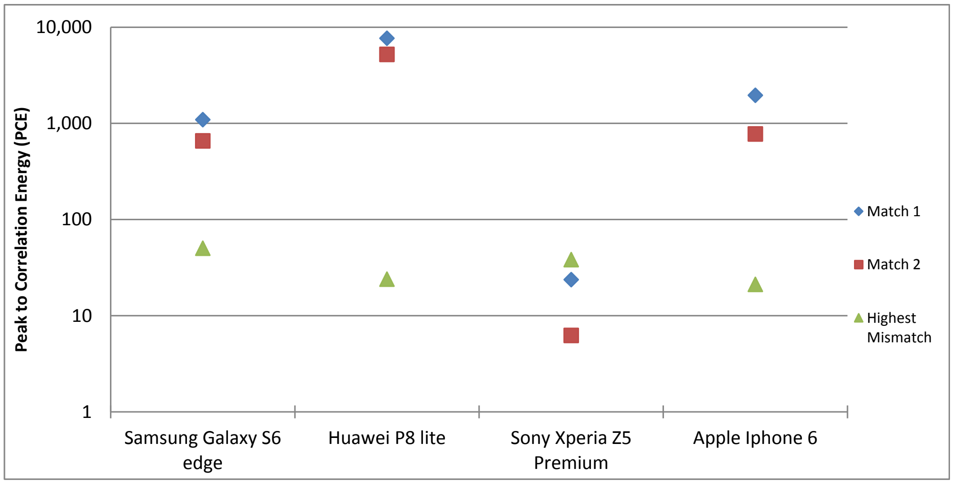

Fig. 1. Results of the source camera identification of the original videos with lower PCE's. The PCE of the two matches and the PCE of the highest mismatch are shown.

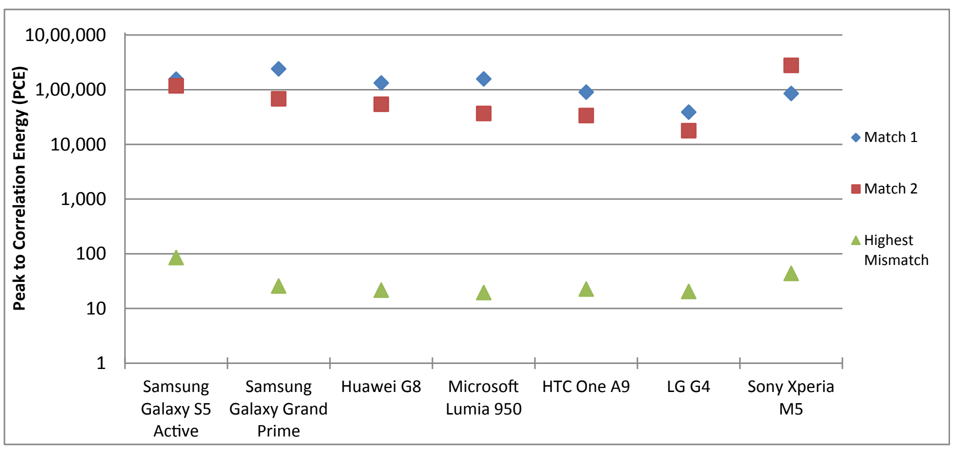

Fig. 2. Results of the source camera identification of the original videos with higher PCE's. The PCE of the two matches and the PCE of the highest mismatch are shown.

with higher PCE's are shown. In both figures a logarithmic scale is used because of the high range of the PCE's.

In Fig. 1 above the results with the lowest PCE are shown. For all cameras the mismatches give PCE's lower than 100. While the PCE's of the matches give much higher values. This means the PRNU-patterns of the original natural videos come to a higher degree of similarity with the flat field video taken with the same camera than with the flat field videos taken with the other cameras. Only for the Sony Xperia Z5 Premium the highest mismatch gives a higher PCE than the two matches what means that the two natural videos come to a smaller degree of similarity with the flat field video taken with the same camera than with a flat field video taken with another camera. Therefore it is not possible to identify the source camera of videos taken with the Sony Xperia Z5 Premium. This camera will be excluded from this research. To replace this camera the Sony Xperia M5 is added to this research. In Table 4 below the added camera is shown.

The results of the PRNU-comparison of the original videos which have higher PCE's and the added camera 11 are shown in Fig. 2 below.

The PCE of the matches in Fig. 2 above differs between 18.000 and 280.000 while the PCE of the mismatches stays below 100 for every camera. The mismatches show the same results as the mismatches in Fig. 1.

In both figures the results of the source camera identification of the original videos show a higher difference between the PCE of the matches and mismatches. Furthermore for 10 of the 11 cameras the source of the original natural videos is correctly determined.

To determine if it is possible to determine if videos originate from the same source, the original natural video 1 (NA1) of each camera are compared with the PRNU-patterns of the original natural video 2 (NA2) of each camera. The results of this comparison are shown in Fig. 3 below.

As shown in Fig. 3 above, the matches give higher PCE's than the mismatches. This means the PRNU-patterns of the two original natural videos of all the investigated cameras come to a bigger degree of similarity compared to each other than compared to a video not originating from the same camera. Therefore the videos are correctly matched to the video originating from the same source. The difference between the PCE of the match and mismatch of the Apple IPhone 6 is, compared to the other cameras very low. This indicates that it may not be possible to determine if videos of this camera originates from the same source when a bigger amount of videos is used.

Comparing these results of the comparison to determine if it is possible to determine if videos originate from the same source (Fig. 3) to the results of the source camera identification in Fig. 1, the PCE's are lower. This is as expected because of the use of flat field

Table 4
Added camera.

Camera	Model	Resolution	Frame rate (FPS)	Extension
11	Sony Xperia M5	1920 × 1080	29	MP4

videos by the source camera identification. The flat field videos used by the source camera identification gives more accurate estimations of the PRNU-pattern. By using flat field videos, much lower amount of detail is present in the video and the camera sensor is illuminated more uniformly (Gisolf et al., 2012; Nederlands Forensisch instituut, 2010; Alles et al., 2007).

WhatsApp version 2.17.79 (android)

Before the videos are transmitted by WhatsApp 2.17.79, the influence of the compression from WhatsApp 2.17.79 on the videos needs to be investigated. Different sending methods are used to investigate variability of compression when sending a video in a different way. Every step is executed in three fold to make sure there is no variability within the same sending method. The results are shown in Table 5 below.

As shown in Table 5 above, the results of the Apple IPhone 6 are not shown. Because of the MOV extension of the videos of the Apple IPhone 6 it was not possible to open or transmit these videos with the Android version of WhatsApp. Therefore the Apple IPhone 6 will be excluded from this part of the research. The results are also not shown per sending method. This has been done because the compression is the same for every method of sending. In appendix A the results per sending method are shown. The WhatsApp version of the receiver did not influence the compression. Also when the videos are transmitted back the IOS WhatsApp version did not compress the videos again. The videos keep the same format as they get by sending the video for the first time. Also the multiple sharing and forwarding did not have influence. The compression is also the same when the videos are transmitted multiple times with the same sending method. There is no variability of the compression within this WhatsApp version. The videos, independent of their original resolution and frame rate, are all converted to a video with a resolution of 640 × 1352 pixels and a frame rate of 30 fps.

Because there is no variability of the compression within this WhatsApp version, the two natural videos and the flat field video of every camera (except the videos from the Apple IPhone 6) are transmitted by this version of WhatsApp.

Constant Rate Factor (CRF)

To compare the PRNU-patterns of the transmitted natural videos with the original flat field videos, the original flat field videos need to be re-encoded with the corresponding resolution. This can be done by using FFmpeg. This is a command line tool that converts videos. To make sure the least possible compression is used, the ideal value for the Constant Rate Factor (CRF) is investigated. Therefore the flat field videos of every camera are converted to multiple videos with the same resolution as the transmitted natural videos (640 × 352) with different CRF values. The CRF values 0, 1, 5, 10, 20 and 50 are used. Every flat field video is also converted to a RAW file and the transmitted flat field video is also included in this part of the investigation. At the end we have 8 videos with different qualities of the flat field video of every camera. The PRNU-patterns of these videos are extracted with PRNUCompare.

To find the ideal value for the CRF, the PRNU-patterns of the transmitted natural videos 1 (NA1) and transmitted natural videos 2 (NA2) are compared with the PRNU-patterns of the flat field

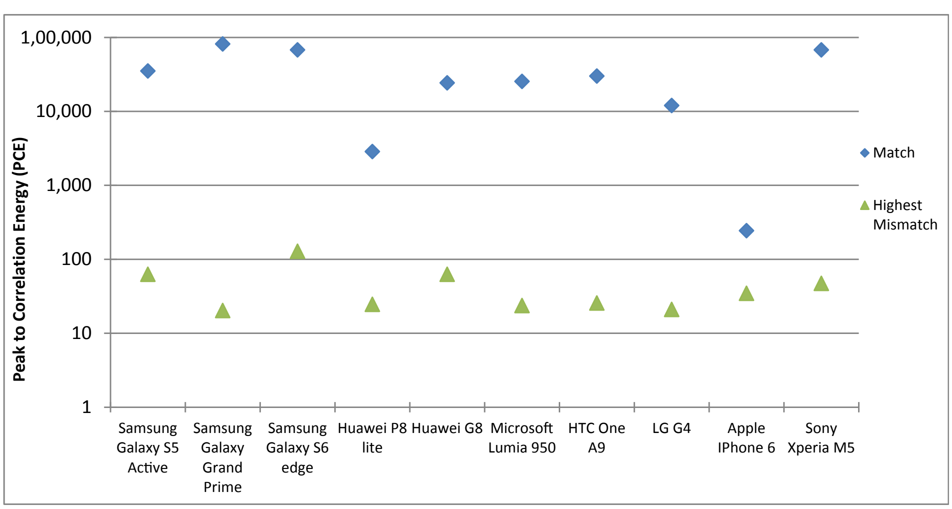

Fig. 3. Results of the comparison between the two original natural videos of each camera, to determine if it is possible to determine if videos originate from the same source. The PCE of the match and the PCE of the highest mismatch are shown.

Table 5
Results of the influence of the compression of WhatsApp 2.17.79 on the videos.

Video	Action	Resolution	Frame rate (fps)	Size (MB)
Galaxy Grand Prime	Original	1280 × 720	29,473	48,964
Microsoft Lumia 950	Original	1920 × 1080	30,005	67,993
Galaxy Grand Prime	After transmitting	640 × 352	30,000	8928
Microsoft Lumia 950	After transmitting	640 × 352	30,000	8125

videos with different qualities. In Fig. 4 below an example of the results of these comparisons is shown. The results of the other cameras are shown in appendix B. The results of the mismatches are not shown because the differences are negligible in comparison to the differences between the matches.

Higher PCE's are achieved with the RAW flat fields, CRF 01 and CRF 05. The PCE differs minimal between these three qualities. By a CRF value of 10 and higher the PCE becomes lower. The flat field videos with a CRF of 50 some PCE are negative what indicates that the PRNU-patterns are inverse to each other.

The flat field videos with a CRF of 0 give surprising results. The PCE is much lower and also the sizes of the videos are smaller. In previous research a CRF of 0 was used (Brouwers and Mousa, 2017). They did not investigate the ideal CRF value and assumed the least possible compression was made by using a CRF of 0. The results in Fig. 4 shown this assumption is not true and that the least possible compression can be made by using RAW videos, CRF 01 or CRF 05.

In this same research (Brouwers and Mousa, 2017) the flat field videos compressed by YouTube gave very low PCE's what made it impossible to identify the source camera. In this research we see that the transmitted flat field videos by WhatsApp 2.17.79 give high PCE's but yet lower than some other qualities.

For 11 of the 18 transmitted natural videos of the 9 different cameras, the highest PCE's are achieved by the comparison with the flat field videos that are converted to RAW videos. Therefore the flat field videos that are converted to RAW videos will be used for the source camera identification with the flat field videos that are not transmitted by WhatsApp.

The difference between correlation of indoor (NA1) versus outdoor (NA2) can be explained by the fact that the indoor images contain less contrasts in the image and also the reference images have been taken indoor.

Source camera identification of the transmitted videos

In this chapter we will take a look at the results of the source camera identification of the videos transmitted by WhatsApp 2.17.79 (Android). Three different kinds of comparisons are done. One comparison between the PRNU-patterns of the transmitted natural videos of each camera and the re-encoded original flat field videos of each camera, to determine if it is still possible to identify the source camera of videos after being transmitted by WhatsApp 2.17.79 (Android). One other comparison between the PRNU-patterns of the transmitted natural videos of each camera and the transmitted flat field videos of each camera, to identify the source camera of videos after being transmitted by WhatsApp 2.17.79 (Android). The last kind of comparison is to determine if it is still possible to determine if videos originate from the same source after being transmitted by WhatsApp 2.17.79 (Android). This is done by comparing the PRNU-patterns of the transmitted natural videos NA1 and NA2 of each camera to each other.

In Fig. 5 below the results of the comparison between the PRNU-patterns of the transmitted natural videos of each camera and the re-encoded original flat field videos of each camera are shown. A logarithmic scale has been used.

For all the nine cameras in Fig. 5 above the sources of the transmitted natural videos are correctly linked. For the most cameras the difference between match and mismatch is high, so the likelihood ratio is also high. In comparison to the results of the original videos in Figs. 1 and 2 in paragraph Original videos, the PCE of the matches and mismatches is lower. Were the mismatches of the original videos are not higher than 100, the mismatches of the transmitted videos are not higher than 10. Because the matches and mismatches give both lower PCE's the difference between match and mismatch persists.

Next the PRNU-patterns of the transmitted natural videos and the transmitted flat field videos are compared. Results of this comparison are shown in Fig. 6 below.

As shown in Fig. 6 above lower PCE's of the matches are achieved with the transmitted flat field videos than with the re-encoded flat field videos. The difference differs between 6 and 980. For this reason it is better to use the re-encoded flat field videos for the source camera identification. But the fact remains the sources of the transmitted videos are correctly identified for all cameras.

Finally the PRNU-patterns of the transmitted natural videos NA1 and NA2 of each camera are compared to each other to determine if

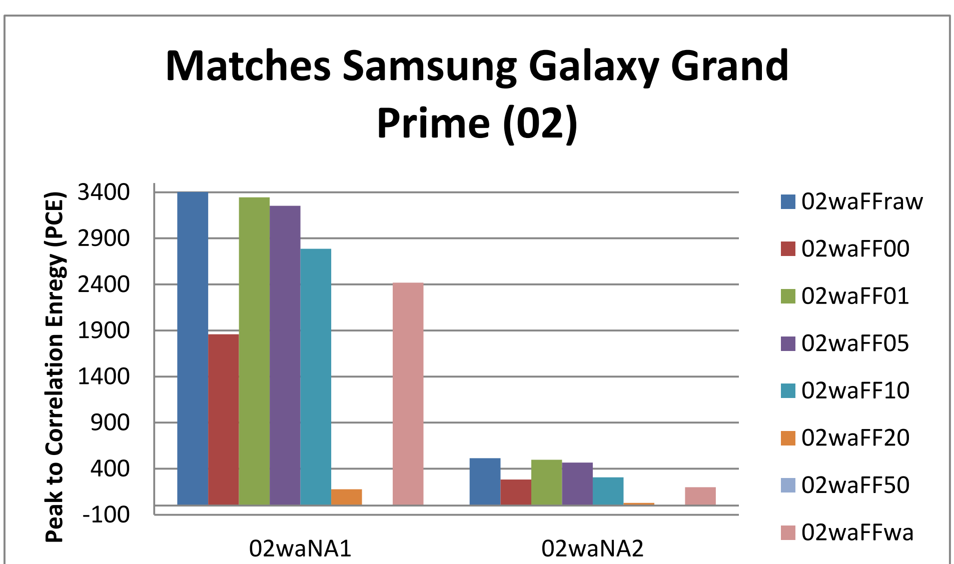

Fig. 4. Results of the matches of the Samsung Galaxy Grand Prime (02). The PRNU-pattern of the transmitted natural video 1 and 2 (NA2) are compared to the flat field videos with different qualities of the Samsung Galaxy Grand Prime (02). The last numbers or letters of the name of the flat field videos (FF) indicates the quality (CRF value 0–50, RAW or compressed with WhatsApp).

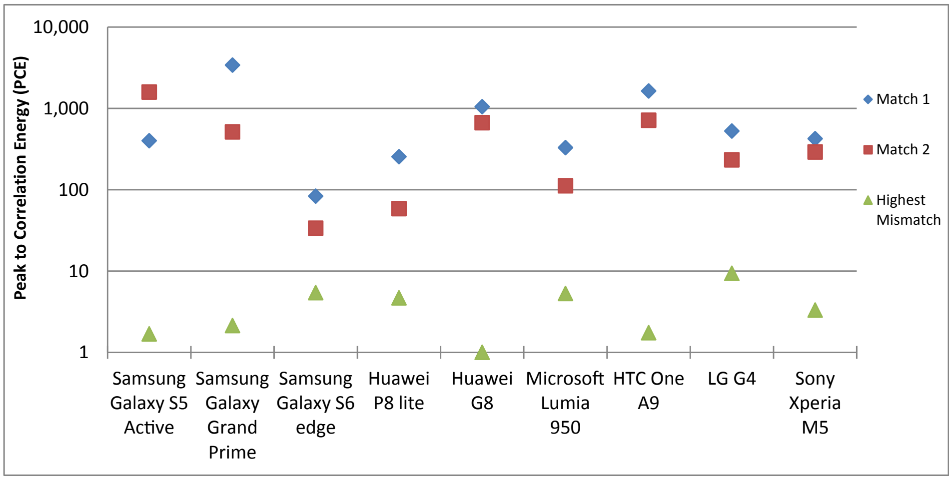

Fig. 5. Results of the source camera identification of the transmitted natural videos with the re-encoded flat field videos. The PCE of the two matches and the PCE of the highest mismatch are shown.

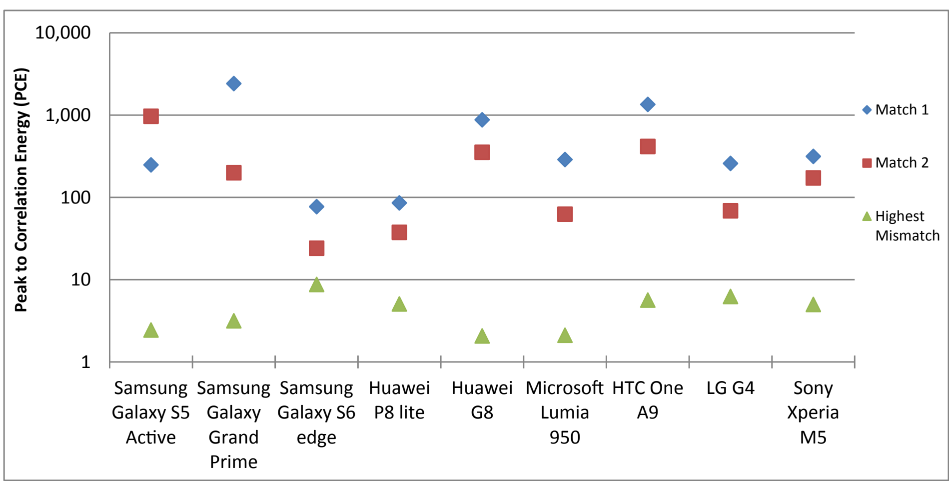

Fig. 6. Results of the source camera identification of the transmitted natural videos with the transmitted flat field videos. The PCE of the two matches and the PCE of the highest mismatch are shown.

it is still possible to determine if videos originate from the same source after being transmitted by WhatsApp 2.17.79 (Android). Results of this comparison are shown in Fig. 7 below.

The PCE is very low as seen in Fig. 7 above. Therefore a normal scale is used instead of a logarithmic one. Compared to the original videos there is almost no difference between match and mismatch. Relatively there is a small difference between the match and mismatch of the Samsung Galaxy S5 Active, Samsung Galaxy Grand Prime and the HTC One A9. Almost no difference between match and mismatch is seen by the other cameras. By the Sony Xperia M5 the highest mismatch is even higher than the match.

WhatsApp version 2.17.20 (IOS)

For this version of WhatsApp the same method will be used as followed by WhatsApp 2.17.79 (Android). Only the CRF value won't be investigated for this version. The original flat field videos will be re-encoded to RAW videos.

At first the influence of the compression from WhatsApp 2.17.20 (IOS) on the videos is investigated. Just as by the Android version of WhatsApp, all different sending methods are investigated in three fold. The same three videos, as with the Android version, are used. The videos of the Apple IPhone 6 can now also be transmitted in contrast to the Android version. The results are shown in Table 6 below.

In appendix C the results with each transmitting method are shown. Just as by the WhatsApp version for Android, the videos are converted to one format. The videos get a new resolution of 480 × 848 pixels. Noticeable is the change of orientation. The original in landscape orientated videos are set to portrait orientation. This is something to take into account when the flat field videos are re-encoded using FFmpeg.

Version 2.17.20 of WhatsApp applies similar compression as the Android version of WhatsApp. Except for the different format the videos are converted into, there is no variability within the same version. The sending method, WhatsApp version of the receiver, and forwarding don't have influence on the compression.

Because there is no variability of the compression within this WhatsApp version, the two natural videos and the flat field video of every camera are transmitted by this version of WhatsApp. Also the

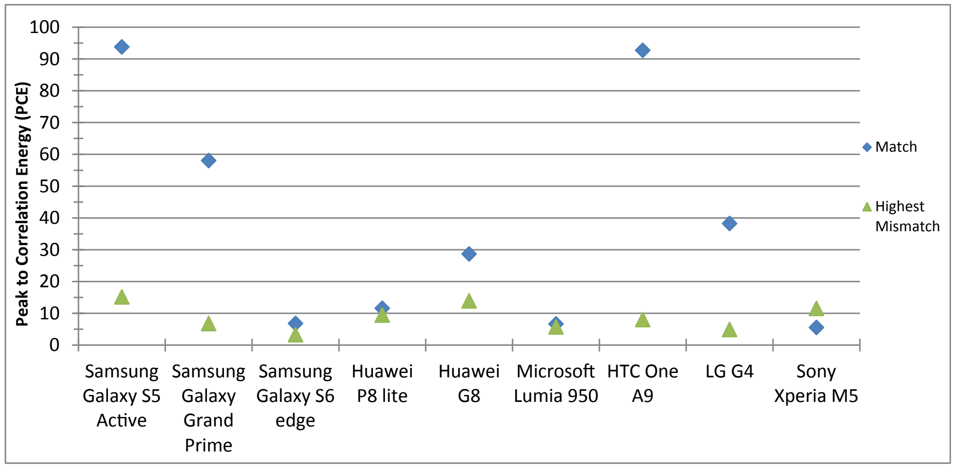

Fig. 7. Results of the comparison between the two transmitted natural videos of each camera, to determine if it is possible to determine if videos originate from the same source. The PCE of the match and the PCE of the highest mismatch are shown.

Table 6
Results of the influence of the compression by WhatsApp 2.17.20 on the videos.

Video	Action	Resolution	Frame rate (fps)	Size (MB)	Extension
Galaxy Grand Prime	Original	1280 × 720	29,473	48,964	MP4
Microsoft Lumia 950	Original	1920 × 1080	30,005	67,993	MP4
Apple IPhone 6	Original	1920 × 1080	29,984	56,344	MOV
Galaxy Grand Prime	After transmitting	480 × 848	29,474	6695	MP4
Microsoft Lumia 950	After transmitting	480 × 848	29,937	6443	MP4
Apple IPhone 6	After sending	480 × 848	29,968	6157	MP4

original flat field videos are re-encoded with the same resolution and orientation using FFmpeg.

Source camera identification of the transmitted videos

Just as by the Android version of WhatsApp, three kinds of comparisons are made: “one comparison with the uploaded flat field videos, one with the re-encoded flat field videos and one between the transmitted natural videos NA1 and NA2”.

In Fig. 8 below the results of the comparison between the PRNU-patterns of the transmitted natural videos and the re-encoded flat field videos are shown.

The PCE of the matches in Fig. 8 above is very low. The highest PCE is only 58. Only at the Huawei G8, HTC One A9 and the Apple IPhone 6 a noticeable difference between match and mismatch is seen, but the difference is minimal. For the other cameras there is none ore almost none difference between match and mismatch and for some cameras the highest mismatch is higher than one of the

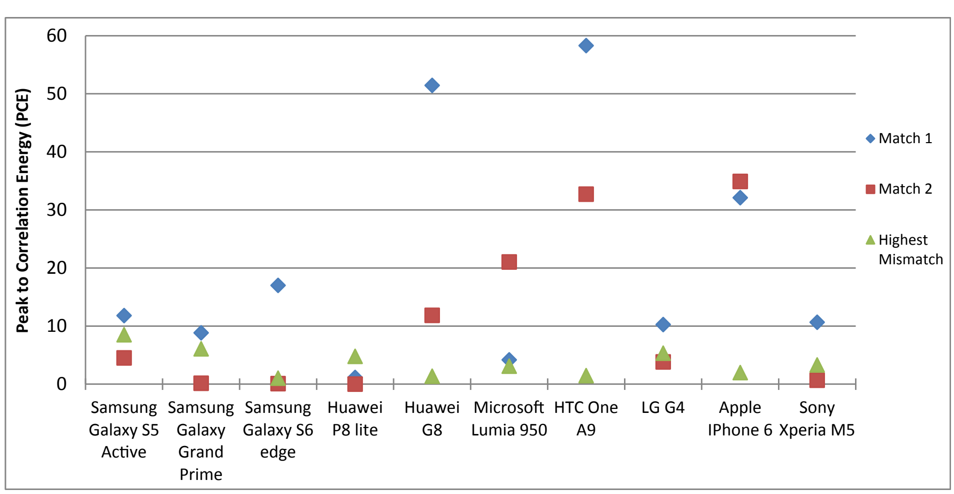

Fig. 8. Results of the source camera identification of the transmitted natural videos with the re-encoded flat field videos. The PCE of the two matches and the PCE of the highest mismatch are shown.

two matches. This makes it impossible to identify the source camera of a video taken with one of these cameras.

No explanation has been found for the low PCE's with the re-encoded videos. Different settings for re-encoding the videos, like different CRF values, are tried, but no better results were obtained.

In Fig. 9 below the results of the comparison between the PRNU-patterns of the transmitted natural videos and the transmitted flat field videos are shown.

In this figure the PCE of the matches is higher than the PCE of the matches from the comparison between the transmitted natural videos and the re-encoded flat field videos. The highest mismatch from the Samsung Galaxy S6 edge, Huawei P8 lite and the LG G4 has got an equal or even higher PCE than one of the two matches. This makes it impossible to identify the source camera of a video taken with one of these cameras. For the videos of the other cameras, the correct sources of both transmitted natural videos are determined. Also a clear difference between match and mismatch is seen.

For determination if multiple videos originate from the same source, the transmitted natural videos of every camera are compared. In Fig. 10 below the results of this comparison are shown.

Fig. 10 above show similar results as the comparison between the transmitted natural videos from the Android version of WhatsApp. The transmitted natural videos do not come to a lower likelihood ratio as can be seen from the low PCE. There is almost no difference between match and mismatch.

Discussion

In Fig. 4 in paragraph Constant rate factor (CRF) the results shown that the re-encoded flat field videos needs to be converted to a RAW video for the minimal loss of quality. The CRF value of 1 in FFmpeg give slightly lower results, but the difference is minimal. A consideration can be made between file size and the minimal difference in quality. The CRF value of 0, that was assumed to deliver minimal loss of quality in earlier studies show a very low PCE (Brouwers and Mousa, 2017). Also the flat field videos that are transmitted by WhatsApp show low PCE.

Furthermore the results of the compression of WhatsApp in Table 5 (paragraph WhatsApp version 2.17.79 (Android)) and Table 6 (paragraph WhatsApp version 2.17.20 (IOS)) show a different compression between the Android and IOS version of

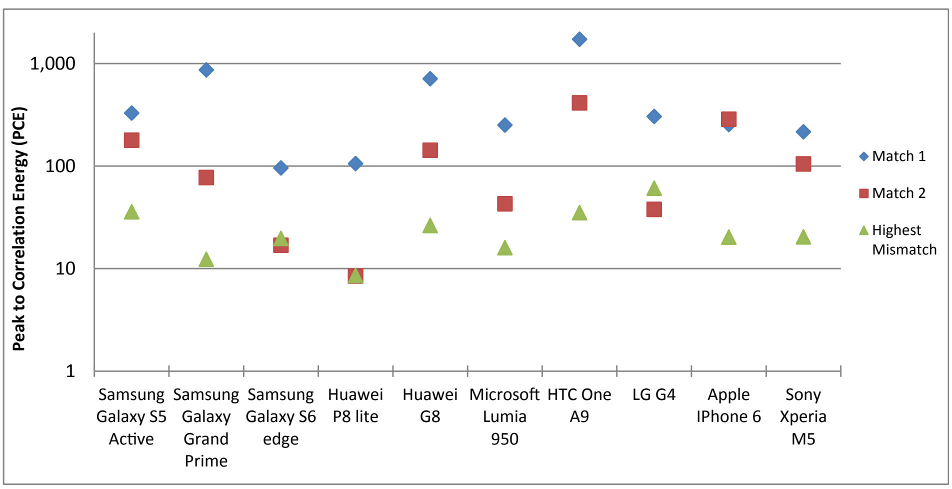

Fig. 9. Results of the source camera identification of the transmitted natural videos with the transmitted flat field videos. The PCE of the two matches and the PCE of the highest mismatch are shown.

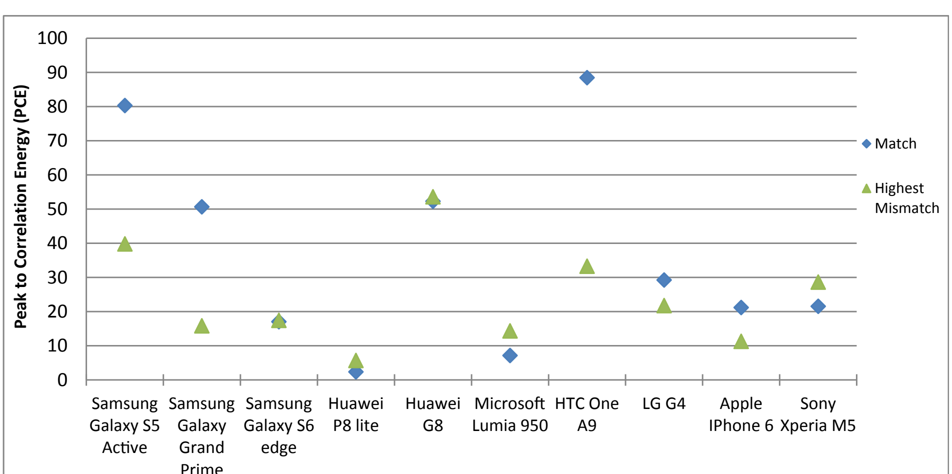

Fig. 10. Results of the comparison between the two transmitted natural videos of each camera, to determine if it is possible to determine if videos originate from the same source. The PCE of the match and the PCE of the highest mismatch are shown.

WhatsApp. The compression variates between different versions of a different operating system, but does not variate between the same version. The videos are converted to one format and stick to that format when the video is forwarded by both WhatsApp versions. The compression of the IOS version of WhatsApp resulted in videos with lower resolution and a smaller file size compared to the compressed videos by the Android version of WhatsApp.

As we evaluate the results of the source camera identification of the videos transmitted by the Android version of WhatsApp in Fig. 5 in paragraph Source camera identification of the transmitted videos, we see the highest likelihood ratios are obtained by the comparison between the transmitted natural videos and the flat field videos re-encoded by FFmpeg. In comparison to the results of the original videos in Figs. 1 and 2 in paragraph Original videos, the PCE of the matches and mismatches is lower. For all the transmitted natural videos of each camera the correct source has been identified.

Results of the source camera identification of the videos transmitted by the IOS version of WhatsApp provided different results. The re-encoded flat field videos by FFmpeg provided lower likelihood ratios in PCE. Therefore the re-encoded flat field videos are not useful for the source camera identification of the IOS version of WhatsApp. Best results are obtained by the comparison between the Transmitted natural videos and the transmitted flat field videos (Fig. 9 in paragraph Source camera identification of the transmitted videos). For seven of the ten investigated cameras the source of the two natural videos are correctly identified. Only for three of the ten investigated camera's the source of the transmitted natural video 2 (match 2) could not be identified correct. For the transmitted natural video 1 (match 1) of these three cameras the source was correctly identified.

Above results indicates that the same sort compression with a minimal loss of quality can be achieved for the Android version of WhatsApp with FFmpeg. For the IOS version of WhatsApp this is not achieved with FFmpeg. If such compression can be achieved for the IOS version of WhatsApp it may be possible to get better results comparable to the results of the Android version of WhatsApp.

The results of the comparison between the transmitted natural video 1 and the transmitted natural video 2 to determine if different videos originates from the same camera show very low PCE. This applies for the Android version of WhatsApp as well for the IOS version of WhatsApp which gave similar results. There is almost no corresponding between the PRNU-patterns which makes it impossible to determine if videos originates from the same source after being transmitted by WhatsApp 2.17.79 for Android and 2.17.20 for IOS. The results in Fig. 3 in paragraph Original videos indicate that this is possible for the original videos.

Conclusions

In this research the possibility to determine the source camera of a video and if different videos originate from the same source camera after being transmitted by WhatsApp 2.17.79 (Android) and 2.17.20 (IOS) is investigated. The results indicate that it is possible for the original videos of the investigated cameras to determine the source camera and to determine if different videos originate from the same source camera with a high likelihood ration. The videos from the same camera come to a higher likelihood ration than videos from other cameras and a clear separation can be made between match and mismatch. After the videos are transmitted by WhatsApp 2.17.79 for Android and WhatsApp 2.17.20 for IOS the results indicates that it is still possible to identify the source camera of the videos for most of the cameras. Lower likelihood ratios are obtained for IOS. For the determination if videos originate from the same source camera the results indicate that it is no longer possible to determine if different videos originate from the same source camera.

Acknowledgments

A special thanks to Arjan Mieremet for his knowledge and expertise in the field of Photo Response Non-Uniformity.

Appendix D. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.diin.2018.02.005.

Appendix A. Results of the compression of WhatsApp 2.17.79 (Android)

Transmitted to WhatsApp 2.17.79 Android:

Table A1
Results of the influence of the compression by WhatsApp 2.17.20 on the videos per transmitting method, Transmitted to WhatsApp 2.17.79 Android.

Video	Action	Resolution	Frame rate (fps)	Size (MB)
Galaxy Grand Prime	Original	1280 × 720	29,473	48,964
Microsoft Lumia 950	Original	1920 × 1080	30,005	67,993
Galaxy Grand Prime	Share from save location with WhatsApp	640 × 352	30,000	8928
Microsoft Lumia 950	Share from save location with WhatsApp	640 × 352	30,000	8125
Galaxy Grand Prime	Add a file to the chat with WhatsApp	640 × 352	30,000	8928
Microsoft Lumia 950	Add a file to the chat with WhatsApp	640 × 352	30,000	8125
Galaxy Grand Prime	Forward from save location with WhatsApp	640 × 352	30,000	8928
Microsoft Lumia 950	Forward from save location with WhatsApp	640 × 352	30,000	8125
Galaxy Grand Prime	Forward by adding a file to the chat with WhatsApp	640 × 352	30,000	8928
Microsoft Lumia 950	Forward by adding a file to the chat with WhatsApp	640 × 352	30,000	8125
Galaxy Grand Prime	Forward by sharing the received video with WhatsApp (only possible for WhatsApp 2.17.79 for Android)	640 × 352	30,000	8928
Microsoft Lumia 950	Forward by sharing the received video with WhatsApp (only possible for WhatsApp 2.17.79 for Android)	640 × 352	30,000	8125
Galaxy Grand Prime	Forward the received video with WhatsApp	640 × 352	30,000	8928
Microsoft Lumia 950	Forward the received video with WhatsApp	640 × 352	30,000	8125

Transmitted to WhatsApp 2.17.20 IOS:

Table A2
Results of the influence of the compression by WhatsApp 2.17.79 on the videos per transmitting method transmitted to WhatsApp 2.17.20 IOS.

Video	Action	Resolution	Frame rate (fps)	Size (MB)
Galaxy Grand Prime	Original	1280 × 720	29,473	48,964
Microsoft Lumia 950	Original	1920 × 1080	30,005	67,993
Galaxy Grand Prime	Share from save location with WhatsApp	640 × 352	30,000	8928
Microsoft Lumia 950	Share from save location with WhatsApp	640 × 352	30,000	8125
Galaxy Grand Prime	Add a file to the chat with WhatsApp	640 × 352	30,000	8928
Microsoft Lumia 950	Add a file to the chat with WhatsApp	640 × 352	30,000	8125
Galaxy Grand Prime	Forward from save location with WhatsApp	640 × 352	30,000	8928
Microsoft Lumia 950	Forward from save location with WhatsApp	640 × 352	30,000	8125
Galaxy Grand Prime	Forward by adding a file to the chat with WhatsApp	640 × 352	30,000	8928
Microsoft Lumia 950	Forward by adding a file to the chat with WhatsApp	640 × 352	30,000	8125
Galaxy Grand Prime	Forward the received video with WhatsApp	640 × 352	30,000	8928
Microsoft Lumia 950	Forward the received video with WhatsApp	640 × 352	30,000	8125

Appendix B. Results of the Constant Rate Factor (CRF)

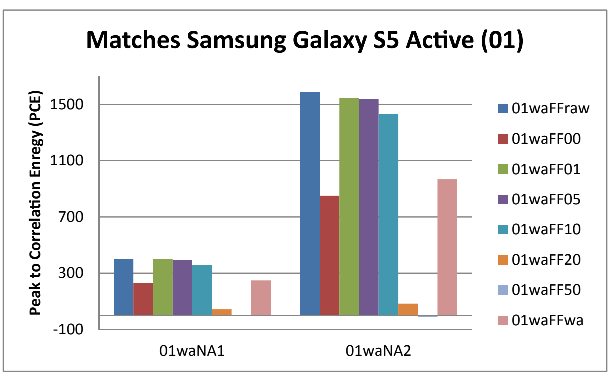

Figure B1. Results of the matches of the Samsung Galaxy S5 Active (01). The PRNU-pattern of the transmitted natural video 1 and 2 (NA2) are compared to the flat field videos with different qualities of the Samsung Galaxy S5 Active (01). The last numbers or letters of the name of the flat field videos (FF) indicates the quality (CRF value 0–50, RAW or compressed with WhatsApp).

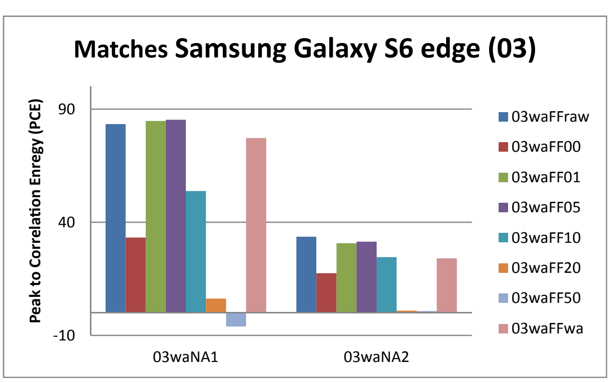

Figure B2. Results of the matches of the Samsung Galaxy S6 edge (03). The PRNU-pattern of the transmitted natural video 1 and 2 (NA2) are compared to the flat field videos with different qualities of the Samsung Galaxy S6 edge (03). The last numbers or letters of the name of the flat field videos (FF) indicates the quality (CRF value 0–50, RAW or compressed with WhatsApp).

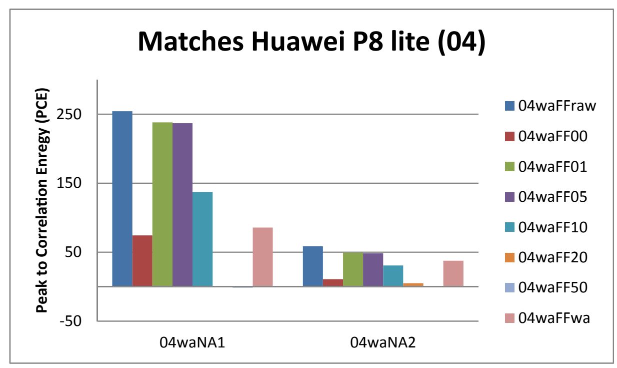

Figure B3. Results of the matches of the Huawei P8 lite (04). The PRNU-pattern of the transmitted natural video 1 and 2 (NA2) are compared to the flat field videos with different qualities of the Huawei P8 lite (04). The last numbers or letters of the name of the flat field videos (FF) indicates the quality (CRF value 0–50, RAW or compressed with WhatsApp).

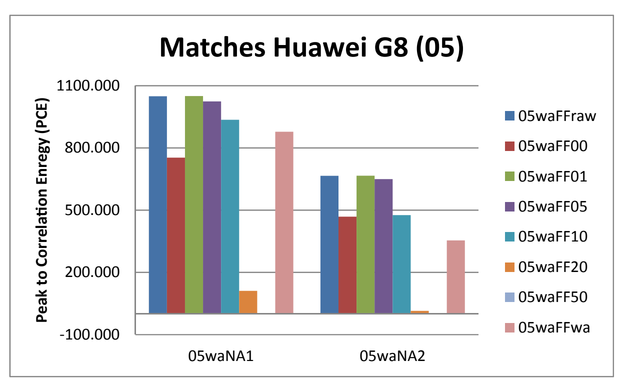

Figure B4. Results of the matches of the Huawei G8 (05). The PRNU-pattern of the transmitted natural video 1 and 2 (NA2) are compared to the flat field videos with different qualities of the Huawei G8 (05). The last numbers or letters of the name of the flat field videos (FF) indicates the quality (CRF value 0–50, RAW or compressed with WhatsApp).

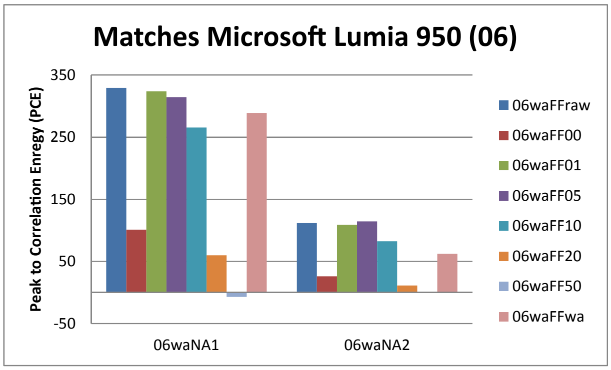

Figure B5. Results of the matches of the Microsoft Lumia 950 (06). The PRNU-pattern of the transmitted natural video 1 and 2 (NA2) are compared to the flat field videos with different qualities of the Microsoft Lumia 950 (06). The last numbers or letters of the name of the flat field videos (FF) indicates the quality (CRF value 0–50, RAW or compressed with WhatsApp).

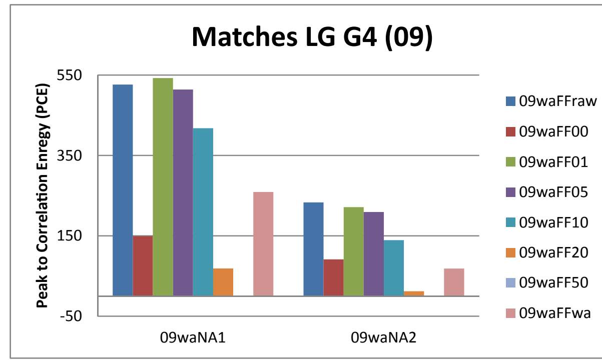

Figure B7. Results of the matches of the LG G4 (09). The PRNU-pattern of the transmitted natural video 1 and 2 (NA2) are compared to the flat field videos with different qualities of the LG G4 (09). The last numbers or letters of the name of the flat field videos (FF) indicates the quality (CRF value 0–50, RAW or compressed with WhatsApp).

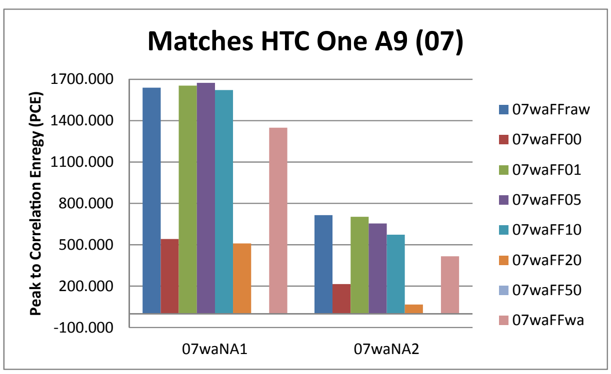

Figure B6. Results of the matches of the HTC One A9 (07). The PRNU-pattern of the transmitted natural video 1 and 2 (NA2) are compared to the flat field videos with different qualities of the HTC One A9 (07). The last numbers or letters of the name of the flat field videos (FF) indicates the quality (CRF value 0–50, RAW or compressed with WhatsApp).

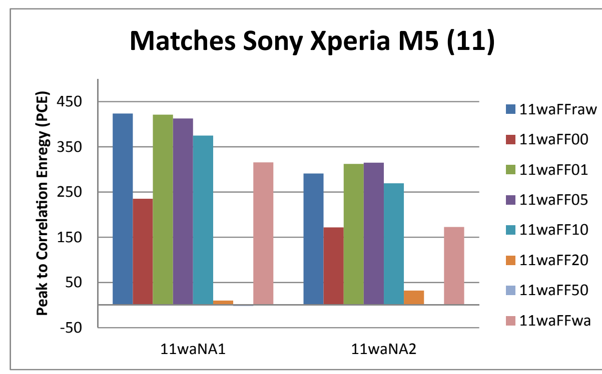

Figure B8. Results of the matches of the Sony Xperia M5 (11). The PRNU-pattern of the transmitted natural video 1 and 2 (NA2) are compared to the flat field videos with different qualities of the Sony Xperia M5 (11). The last numbers or letters of the name of the flat field videos (FF) indicates the quality (CRF value 0–50, RAW or compressed with WhatsApp).

Appendix C. Results of the compression of WhatsApp 2.17.20 (IOS)

Transmitted to WhatsApp 2.17.20 IOS.

Table C1
Results of the influence of the compression by WhatsApp 2.17.20 on the videos per transmitting method, Transmitted to WhatsApp 2.17.20 IOS.

Video	Action	Resolution	Frame rate (fps)	Size (MB)
Galaxy Grand Prime	Original	1280 × 720	29,473	48,964
Microsoft Lumia 950	Original	1920 × 1080	30,005	67,993
Apple IPhone 6	Original	1920 × 1080	29,984	56,344
Galaxy Grand Prime	Share from save location with WhatsApp	480 × 848	29,474	6695
Microsoft Lumia 950	Share from save location with WhatsApp	480 × 848	29,937	6443
Apple IPhone 6	Share from save location with WhatsApp	480 × 848	29,968	6157
Galaxy Grand Prime	Add a file to the chat with WhatsApp	480 × 848	29,474	6695
Microsoft Lumia 950	Add a file to the chat with WhatsApp	480 × 848	29,937	6443
Apple IPhone 6	Add a file to the chat with WhatsApp	480 × 848	29,968	6157
Galaxy Grand Prime	Forward from save location with WhatsApp	480 × 848	29,474	6695
Microsoft Lumia 950	Forward from save location with WhatsApp	480 × 848	29,937	6443
Apple IPhone 6	Forward from save location with WhatsApp	480 × 848	29,968	6157
Galaxy Grand Prime	Forward by adding a file to the chat with WhatsApp	480 × 848	29,474	6695
Microsoft Lumia 950	Forward by adding a file to the chat with WhatsApp	480 × 848	29,937	6443
Apple IPhone 6	Forward by adding a file to the chat with WhatsApp	480 × 848	29,968	6157
Galaxy Grand Prime	Forward the received video with WhatsApp	480 × 848	29,474	6695
Microsoft Lumia 950	Forward the received video with WhatsApp	480 × 848	29,937	6443
Apple IPhone 6	Forward the received video with WhatsApp	480 × 848	29,968	6157

Transmitted by WhatsApp 2.17.79 Android.

Table C2
Results of the influence of the compression by WhatsApp 2.17.20 on the videos per transmitting method, Transmitted to WhatsApp 2.17.79 Android.

Video	Action	Resolution	Frame rate (fps)	Size (MB)
Galaxy Grand Prime	Original	1280 × 720	29,473	48,964
Microsoft Lumia 950	Original	1920 × 1080	30,005	67,993
Apple IPhone 6	Original	1920 × 1080	29,984	56,344
Galaxy Grand Prime	Share from save location with WhatsApp	480 × 848	29,474	6695
Microsoft Lumia 950	Share from save location with WhatsApp	480 × 848	29,937	6443
Apple IPhone 6	Share from save location with WhatsApp	480 × 848	29,968	6157
Galaxy Grand Prime	Add a file to the chat with WhatsApp	480 × 848	29,474	6695
Microsoft Lumia 950	Add a file to the chat with WhatsApp	480 × 848	29,937	6443
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Microsoft Lumia 950	Forward from save location with WhatsApp	480 × 848	29,937	6443
Apple IPhone 6	Forward from save location with WhatsApp	480 × 848	29,968	6157
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Microsoft Lumia 950	Forward by adding a file to the chat with WhatsApp	480 × 848	29,937	6443
Apple IPhone 6	Forward by adding a file to the chat with WhatsApp	480 × 848	29,968	6157
Galaxy Grand Prime	Forward by sharing the received video with WhatsApp (only possible for WhatsApp 2.17.79 for Android)	480 × 848	29,474	6695
Microsoft Lumia 950	Forward by sharing the received video with WhatsApp (only possible for WhatsApp 2.17.79 for Android)	480 × 848	29,937	6443
Apple IPhone 6	Forward by sharing the received video with WhatsApp (only possible for WhatsApp 2.17.79 for Android)	480 × 848	29,968	6157
Galaxy Grand Prime	Forward the received video with WhatsApp	480 × 848	29,474	6695
Microsoft Lumia 950	Forward the received video with WhatsApp	480 × 848	29,937	6443
Apple IPhone 6	Forward the received video with WhatsApp	480 × 848	29,968	6157

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