A FORENSIC ANALYSIS OF RING CAMERA VIDEO: SENSOR-BASED IDENTIFICATION AND MANIPULATION DETECTION

by

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Thesis directed by Associate Professor Catalin Grigoras

ABSTRACT

This study evaluates the reliability of Ring camera footage as digital evidence through a dual-layer forensic approach. As consumer surveillance footage becomes increasingly used in legal contexts, ensuring its authenticity is critical. This research combines Photo Response Non-Uniformity (PRNU) analysis for source camera identification with structural and metadata-based techniques for detecting video manipulation. Controlled experiments are conducted using multiple camera devices to generate both original and altered video datasets. The findings assess the effectiveness of these forensic methods in identifying source devices and detecting tampering, contributing to the broader evaluation of consumer-generated video as reliable forensic evidence.

Video data was collected from two Ring cameras and a TP-Link Tapo C100 in a controlled environment. Frames were extracted and processed in MATLAB to isolate sensor noise patterns and generate reference fingerprints. A test clip was then compared to these fingerprints using correlation analysis. Results showed a strong correlation (0.8959) between a test clip and its source camera, while comparison with a non-source camera produced a significantly lower correlation (0.0661). These findings suggest that PRNU-based analysis can effectively distinguish between source and non-source devices under controlled conditions.

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

Approved: Catalin Grigoras

DEDICATION

To my brilliant girl, Jemma — this is for you. To my parents, thank you for your unconditional love and encouragement. To Jasmine, your patience and support were critical to my success in this program. I will be forever grateful.

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ABBREVIATIONS

PRNU - Photo Response Non-Uniformity

FFmpeg - Fast Forward Moving Picture Experts Group (multimedia processing tool)

GOP - Group of Pictures

MP4 - Moving Picture Experts Group-4 Part 14 (video container format)

MOV - Apple QuickTime Movie File Format

H.264 - Advanced Video Coding (AVC)

H.265 - High Efficiency Video Coding (HEVC)

FPS - Frames Per Second

SNR - Signal-to-Noise Ratio

MATLAB - Matrix Laboratory

EXIF - Exchangeable Image File Format

NCMF- National Center for Media Forensics

SHA-256 - Secure Hash Algorithm 256-bit

CHAPTER I

INTRODUCTION

The use of Ring camera footage in investigative and legal contexts has increased significantly as consumer surveillance devices have become more accessible and widely adopted. Advances in technology have reduced the cost of these devices, in some cases leading to subsidized or freely distributed hardware, allowing widespread deployment across residential and commercial environments. As a result, Ring cameras now function as a pervasive form of digital observation, capturing a wide range of events from criminal activity to routine daily interactions.

Originally introduced as a crowdfunded product under the name *Doorbot*, Ring was later acquired by Amazon in 2018 for approximately one billion dollars (Reuters, 2018). Since its acquisition, Ring has grown to become a dominant force in the doorbell camera market, contributing to what is effectively one of the largest privately operated surveillance networks in the United States. This rapid expansion raises important questions regarding data integrity, security, and the reliability of recorded footage when used as evidence.

The Ring camera models used in this study were configured at their default recording settings, and the resulting files were examined directly using FFprobe to confirm resolution, codec, frame rate, and bitrate values. Prior research on Ring acquisition methods found that Ring video files may be obtained through multiple acquisition or download paths and that these methods may produce differences in resolution, metadata, and embedded timestamps (Epstein et al, 2021). Given the wide array of methods that can be utilized for obtaining Ring acquisition, it is important to note that the method used in this study utilized the Ring native iOS app, using a free tiered Ring Plan for storing and transferring of the video files. The files were recorded using a live view to ensure the clips that were captured remained consistent. Once the footage required was recorded, the share feature was used, and the clip was sent from an iPhone to a Mac Mini via Airdrop. Airdrop was chosen as a means of consistency and reliability, maintaining overall quality. It is noted through Apple (2026) documentation which indicates that iPhone users can enable "All Photos Data" in the photo application when sharing through Airdrop to send videos in their original format, including metadata and edit history.

While this accessibility increases usability and provides security protection to many, it also introduces potential risks related to unauthorized modification or manipulation. When such footage is presented in legal proceedings, the ability to verify its authenticity becomes critically important. Visual inspection alone is often insufficient to determine whether a video has been altered, necessitating deeper forensic analysis at both the file and sensor levels.

This study evaluates whether Ring camera footage can be reliably analyzed for signs of manipulation through examination of structural video characteristics, encoding behavior, and metadata inconsistencies. Manipulated video samples are compared against original recordings to identify detectable differences introduced through controlled alterations. In addition, this study incorporates Photo Response Non-Uniformity (PRNU) analysis to determine whether individual clips can be attributed to a specific recording device, rather than a generalized camera model.

Ensuring the integrity of digital video evidence is essential in contexts where the outcome of legal proceedings may depend on the authenticity of recorded footage. This study evaluates the reliability of home surveillance camera footage through a dual-layer forensic approach combining sensor-level identification and file-level manipulation detection.

Purpose of the Study

The purpose of this study is to evaluate the reliability of consumer-generated video footage, specifically from Ring devices, as digital evidence through a dual-layer forensic approach. As surveillance cameras become increasingly prevalent in residential and public environments, video footage captured by these devices is frequently introduced in legal and investigative contexts. Ensuring the authenticity and source of such footage is critical for its admissibility and reliability. This research applies two forensic methods: Photo Response Non-Uniformity (PRNU) analysis for source camera identification and structural analysis for detecting potential video manipulation. By combining sensor-level fingerprinting with file-level examination, this study aims to determine whether a video can be reliably attributed to a specific device and whether common editing operations introduce detectable changes within the file structure. Through controlled experimentation using multiple camera devices and manipulated video samples, this study seeks to provide a practical framework for evaluating both the origin and integrity of consumer surveillance footage. The findings contribute to the broader field of digital video forensics by demonstrating the effectiveness of a combined analytical approach in real-world scenarios.

Research Questions

1. Can PRNU-based analysis reliably identify the source camera of video footage recorded by consumer surveillance devices?
2. Can common video manipulations, such as trimming, re-encoding, and resizing, be detected through structural and metadata-based analysis?
3. Does a combined dual-layer approach (PRNU and structural analysis) improve the ability to evaluate both the origin and integrity of digital video evidence?

Scope and Limitations

The scope of the research is limited to a controlled experimental environment using three consumer-grade surveillance cameras. All video clips were recorded under consistent lighting conditions and standardized positioning to minimize variability and ensure comparability across devices. The PRNU analysis is limited to a small dataset consisting of multiple short video clips per device, with reference fingerprints generated from a subset of recordings and tested against individual clips. While the results demonstrate clear separation between source and non-source devices, the findings are based on controlled conditions and may not fully represent performance in real-world environments with varying lighting, motion, compression levels, and recording settings. The manipulation analysis is limited to a defined set of common editing operations, including trimming, re-encoding, and resolution change.

Despite these limitations, the study provides a focused and practical evaluation of both source camera attribution and manipulation detection, demonstrating the effectiveness of a combined forensic approach under controlled conditions.

Previous Research

Previous research in digital media forensics has shown that images and videos may contain device-specific traces useful for source attribution. Additionally, previous research has also shown that metadata and structural characteristics of video files can provide important forensic information. The importance of digital video forensics has grown with the widespread use of consumer recording devices. As these technologies have become more accessible, they are often present during criminal activity, serving as tools for documentation, communication, and evidence collection. As a result, video footage has become a key component in modern investigations, requiring reliable methods for analysis and authentication.

While previous research has examined PRNU source attribution, video compression, and metadata-based forensic analysis, fewer studies have applied these methods specifically to consumer surveillance systems such as Ring cameras. This study aims to address that gap by analyzing Ring camera footage through a dual layer analysis approach.

CHAPTER II

MATERIALS

This study utilizes three video recording devices to evaluate both PRNU-based camera identification and video manipulation detection. Two devices were manufactured by Ring, consisting of one indoor model and one outdoor model. As a third device, a TP-Link Tapo C100 was included as a comparison device to introduce variation in encoding formats and device characteristics. All three cameras were used in PRNU reference fingerprint generation to assess sensor-level uniqueness across devices. For manipulation testing, the indoor Ring camera was used to create and analyze altered video samples. Video data was captured and transferred using an Apple iPhone 17 Pro Max, providing a consistent and practical workflow representative of typical user behavior. Processing and analysis were conducted using a MacBook Pro and Mac mini, which were used to perform video manipulation, frame extraction, and PRNU analysis. All cameras were operated using their default recording settings with no manual adjustments. Video clips were recorded in a controlled indoor environment to ensure consistency across devices. Natural lighting conditions were kept as even as possible, and the camera was positioned at approximately the same distance from the subject, maintaining similar framing and field of view. The camera was placed on a stable surface to eliminate motion during recording. The indoor Ring camera required a constant power supply via USB connection and operated on a 2.4 GHz wireless network.

Figure 1. Ring Indoor Cam, Outdoor Cam, Tapo C100

The following software applications were used in this study:

- FFmpeg 8.1
- MATLAB R2025b (Update 5)
- Ring Native iOS application
- Tapo Native iOS application
- iOS 26
- MacOS 26.0

All video files were transferred directly from each camera's native application to preserve as much original file structure and maintain dataset integrity.

CHAPTER III

METHODOLOGY

This study adopts a dual-layer digital forensic approach to evaluate both video manipulation detection and source camera attribution. The methodology combines structural (file-level) analysis with sensor-level analysis to provide a comprehensive assessment of video authenticity. Manipulation testing is conducted on a predefined set of video clips recorded from Ring and TP-Link Tapo cameras. The purpose of this testing is to determine whether common video manipulations can be detected through analysis of video structure, metadata, and encoding behavior. In parallel, PRNU analysis is used to evaluate whether individual cameras can be reliably identified through sensor-level fingerprinting. This allows for verification of a video source by comparing extracted noise patterns against reference fingerprints. All experiments are conducted in a controlled environment in which known manipulations are applied to original video clips. These manipulated clips are then directly compared to their original counterparts to assess the impact of each manipulation type on both structural forensic indicators and sensor-level fingerprints. Together, this approach enables evaluation of whether a video has been altered and whether its source camera can be accurately identified, providing a more robust framework for digital video forensic analysis.

To preserve the integrity of the original video data, all source files were maintained in a read-only state and were not modified during the analysis process. Copies of the original video files were created and organized into separate working directories for all processing tasks. This separation between original and working copies aligns with standard forensic practices by reducing the risk of unintentional modification and maintaining a clear distinction between source evidence and processed data (NIST, 2022, SWGDE, 2018). All experimental operations were performed exclusively on these working copies to ensure that the original recordings remained unchanged. This separation between original and working data aligns with standard forensic practices by minimizing the risk of unintentional modification and maintaining a clear distinction between source evidence and processed data. In this thesis, ‘original’ is defined as the first video file received by the examiner via the platform’s native export/download function (Ring/Tapo app export or Ring.com download), prior to any researcher-applied processing. Because these systems are commonly cloud-managed and may not provide access to an on-device forensic image or the provider’s internal storage representation, the export/download artifact is treated as the operational original for analysis (SWGDE, 2018; NIST, 2022).

Stream Hash Verification

In addition to SHA-256 hashing verification, stream-level hashing was also used as an additional verification step to ensure the integrity of the encoded video stream. In comparison to whole-file hashing, stream hashing focuses on the encoded stream data itself allowing the examiner to distinguish between changes affecting the entire file container and changes solely affecting the video stream. For each file, a stream hash was generated using FFmpeg’s stream hash function to document the encoded media streams separately from the complete container file. The results are recorded in appendix E. The original SHA-256 serves as a baseline reference. This additional step in verification ensures that the integrity of the file-level data has not been compromised, and it ensures consistency with data as it gets transferred and analyzed.

PRNU – Photo Response Non-Uniformity

Photo Response Non-Uniformity (PRNU) is a sensor-based noise pattern unique to each digital imaging device and can be used as a fingerprint for source camera identification. PRNU arises from inherent manufacturing imperfections in imaging sensors, resulting in slight variations in pixel sensitivity to light. These variations form a unique and stable pattern, often referred to as a sensor fingerprint, which is embedded in all media captured by a given device. Because PRNU is present as a high-frequency noise component within an image or video frame, it can be extracted through a denoising process that isolates the residual noise from the visual content. By aggregating noise residuals across multiple frames, a reference fingerprint for a specific camera can be generated. This fingerprint can then be compared against noise extracted from a test video to determine whether the content originated from the same device. The PRNU extraction workflow used in this study was based on the sensor pattern noise method described by Lukáš, Fridrich, and Goljan (2006).

PRNU analysis is conducted independently of manipulation detection to determine whether each camera produces a consistent and identifiable sensor-level signature. In this study, PRNU was extracted using a wavelet-denoising residual-based algorithm implemented in MATLAB version R2025b Update 5 and using FFmpeg version 8.1 for image extraction. Individual video frames were extracted from each camera clip. Each frame was then converted into a numerical image matrix for processing. A wavelet-based denoising filter was applied to suppress visible scene content while preserving high-frequency sensor noise. A denoising filter is applied to estimate image content, and the residual noise is obtained by subtracting the denoised image from the original frame. Noise residuals from multiple frames are aggregated to enhance the underlying PRNU signal while reducing random noise. The resulting averaged residual forms a reference fingerprint for each camera device. Extracted noise residuals from test clips are compared against reference fingerprints using normalized correlation. Higher correlation values indicate a stronger likelihood that the footage originated from the same camera, while lower values indicate a different source. These results provide a quantitative measure of camera attribution and serve as a validation step prior to manipulation analysis.

The PRNU dataset consisted of multiple clips recorded from each camera device. Three clips per device were used to generate reference fingerprints, while a fourth clip was reserved for testing and correlation analysis. All PRNU source clips used for fingerprint generation, and testing were verified against SHA256 hashes recorded at acquisition (Appendix B). This ensured the reference and test datasets remained unchanged prior to frame extraction and PRNU processing.

Accurate PRNU extraction requires minimizing interference from scene content. Complex textures, edges, and motion introduce additional high-frequency information that can obscure or contaminate the underlying sensor noise pattern. As a result, controlled capture conditions are commonly used in PRNU-based studies to improve signal clarity and reliability.

In this study, a uniform white wall was used as the primary capture scene for PRNU extraction. The use of a flat, evenly lit surface reduces the presence of strong edges and textures, allowing the sensor noise pattern to be more effectively isolated. This controlled environment enhances the signal-to-noise ratio of the extracted PRNU and improves the consistency of the resulting reference fingerprint. Additionally, all recordings were conducted under stable lighting conditions to avoid fluctuations that could impact pixel responses. By maintaining consistent environmental variables, the study ensures that variations observed in the PRNU analysis are attributable to the imaging sensor rather than external factors.

The use of controlled scenes is particularly important in establishing baseline PRNU performance prior to applying the method to more complex, real-world footage. By first confirming that each camera produces a distinct and identifiable fingerprint under ideal conditions, the study can more accurately evaluate the reliability of PRNU in subsequent testing phases. Correlation values were interpreted relative to expected baseline behavior observed in PRNU analysis. Higher correlation values indicate a stronger similarity between a test clip and a reference fingerprint, suggesting that the footage originated from the same device. Lower correlation values indicate weak similarity and are associated with non-matching devices.

In this study, correlation values approaching 1.0 were considered strong matches, while values near zero were interpreted as non-matches. These interpretations were used to evaluate the effectiveness of PRNU-based source attribution across all tested devices

Table 1. PRNU Dataset Summary

Camera	**Clip Name**	**Purpose**	**Duration**	**Notes**
CamA	Clip001	Reference	~13	Used for fingerprint generation
CamA	Clip002	Reference	~13	Used for fingerprint generation
CamA	Clip003	Reference	~13	Used for fingerprint generation
CamA	Clip004	Test	~13	Used for correlation testing
CamB	Clip001	Reference	~13	Using for fingerprint generation
CamB	Clip002	Reference	~13	Used for fingerprint generation
CamB	Clip003	Reference	~13	Used for fingerprint generation
CamB	Clip004	Test	~13	Used for correlation testing
CamC	Clip001	Reference	~13	Used for fingerprint generation
CamC	Clip002	Reference	~13	Used for fingerprint generation
CamC	Clip003	Reference	~13	Used for fingerprint generation
CamC	Clip004	Test	~13	Used for correlation testing

Manipulation Detection

This phase of the study evaluates whether controlled video manipulations can be detected through forensic analysis of file structure, encoding behavior, and metadata. The focus is on identifying non-visual indicators of tampering within the video file. Manipulation testing is conducted using the standard video dataset described in this study. Original clips serve as baseline references for comparison against manipulated versions. A series of controlled manipulations are applied to duplicate copies of the original video clips to simulate realistic editing scenarios. These manipulations include trimming, re-encoding, and resizing. All manipulations are performed using FFmpeg V8.1 to ensure consistency and reproducibility. The FFmpeg settings were documented for each manipulation condition. Trimming was performed by specificizing the start time and duration of the output clip. Manipulated files are stored separately from original recordings to maintain data integrity. The baseline (original) manipulation clip was hashed (SHA-256) at acquisition and verified prior to creating manipulated derivatives. SHA-256 hashes were also computed for each manipulated output to uniquely identify each derivative file (Appendix B). In addition to SHA-256, stream hash values were verified and noted (Appendix E). The manipulation dataset was created using a single baseline video clip, with controlled edits applied to generate multiple manipulated versions. Each manipulation was designed to simulate common real-world editing operations while isolating specific changes for analysis.

Table 2. Manipulation Dataset Summary

File Name	Camera	Type	Manipulation	Duration	Notes
CAMA_MANIP_001_ORIG	CamA	Original	NONE	13.486	Baseline reference clip
CAMA_MANIP_001_TRIM	CamA	Manipulated	TRIMMING	6	Shortened segment derived from original.
CAMA_MANIP_001_RESIZE	CamA	Manipulated	RESOLUTION CHANGE	13.486	Scaled to 640x360
CAMA_MANIP_001_H265	CamA	Manipulated	RE-ENCODING	13.486	Converted to H.265 codec

Types of Manipulation

To evaluate the reliability of forensic analysis techniques in detecting altered video content, this study applies to three common forms of video manipulation: trimming, resizing, and re-encoding. These manipulation types were selected because they represent realistic and frequently encountered alterations in digital video evidence while introducing varying levels of structural and visual impact.

Trimming

Trimming is the deliberate removal of temporal content from a video (e.g., deleting frames at the beginning/end or excising an interval) without necessarily altering the remaining imagery. At the file level, trimming commonly results in a reduced reported duration and may introduce timing discontinuities or re-indexing within the container (e.g., DTS/PTS progression), altered edit lists, and GOP boundary anomalies such as shifted IDR placement or changed GOP cadence when the clip is re-mixed or re-encoded. Because trimming can omit context or critical events while leaving the remaining footage visually plausible, it is a significant integrity concern and should be interpreted as potential selective removal rather than natural recording behavior. In this study, trimming was performed using FFmpeg by specifying the start time and duration of the output clip. The -c copy option was used to copy the existing encoded stream without re-encoding. FFprobe was then used to verify the resulting file duration, codec, resolution, frame rate, and stream metadata. The following command lines was executed in terminal:

```
ffmpeg -i "original_clip.mp4" -ss 00:00:02 -t 00:00:08 -c copy "trimmed_clip.mp4"

ffprobe -v error -show_format -show_streams "trimmed_clip.mp4"
```

Resizing

Resizing refers to changing the spatial dimensions of a video while preserving the general visual content and duration. In this study, the resized derivative was scaled to 640x360. This manipulation is expected to alter the resolution, pixel dimensions, bitrate, and possibly compression behavior. Although resizing does not necessarily change the timeline of the video, it can modify structural and encoding characteristics that distinguish the derivative file from the original. Resizing manipulation was performed using FFmpeg's scale video filter. Because no alternate interpolation flag was manually specified in the command, the resizing operation used the default interpolation behavior of the installed FFmpeg version. FFmpeg version 8.1 uses bicubic interpolation as the default scaler flag; therefore, the resolution-change condition in this study was performed using default bicubic interpolation.

```
ffmpeg -i input.mp4 -vf scale=640:360 output_resize.mp4

ffprobe -v error -show_format -show_streams "output_clip.mp4"
```

Re-encoding

Re-encoding refers to the process of decoding and then re-compressing a video using the same or a different codec, bitrate, or encoding configuration. Unlike splicing or frame deletion, re-encoding does not necessarily alter the visible content of a video but modifies how the data is stored and compressed. This process can significantly impact both structural and sensor-level forensic analysis. Re-encoding may alter compression artifacts, quantization parameters, and bitrate distribution, while also degrading or weakening the Photo Response Non-Uniformity (PRNU) signal used for source camera identification. Additionally, re-encoded files may exhibit changes in container metadata and encoding signatures, which can be analyzed to identify inconsistencies with original recordings. Re-encoding was performed using FFmpeg by specifying the target video codec, compression level, and encoding preset. The following command line was executed in terminal:

```
ffmpeg -i "original_clip.mp4" -c:v libx265 -crf 28 -preset medium -an
"reencoded_h265_clip.mp4"
ffprobe -v error -show_format -show_streams "reencoded_h265_clip.mp4"
```

Summary

These three manipulation types provide a controlled framework for testing the effectiveness of both structural and sensor-based forensic methods. Resizing and frame deletion primarily introduce temporal and structural inconsistencies, while re-encoding affects compression characteristics and sensor-level signals. By evaluating each manipulation independently, this study aims to assess how different forms of alteration impact the detectability and reliability of digital video forensic techniques. Each manipulated clip was directly compared to the original baseline to identify structural differences introduced by the editing process.

Structural analysis focused on identifying measurable differences between original and manipulated video files. The original clip served as the baseline reference, with its duration, bitrate, resolution, codec, and frame rate used as comparison points. Manipulated clips were expected to exhibit deviations from these baseline values depending on the type of edit applied. For example, trimming was expected to reduce duration, resolution changes were expected to alter frame dimensions, and re-encoding was expected to affect codec type and compression characteristics. These expected differences provided a basis for identifying whether a video had undergone modification.

CHAPTER IV

RESULTS

This section presents the findings of the experimental analysis conducted in this study. The results are organized into two primary components: PRNU-based camera identification and video manipulation detection. The PRNU analysis evaluates the ability to attribute video clips to their source camera using sensor-level fingerprints, while the manipulation analysis examines whether controlled edits introduce detectable changes in file-level properties. Together, these results provide a comprehensive assessment of both the origin and integrity of the analyzed video footage under controlled conditions. Prior to analysis, original exported files were re-verified against the SHA-256 manifests to confirm integrity; all values matched (Appendix B). PRNU and manipulation analyses were performed on verified working copies.

PRNU Results

PRNU-based analysis was conducted to evaluate whether video clips could be attributed to their source camera. PRNU correlation analysis is commonly used to compare extracted sensor noise from questioned media against a known reference fingerprint, with stronger correlation values indicating greater similarity between the test material and the reference device pattern (Lukáš et al., 2006; Chen et al., 2008). Reference fingerprints were generated for each device using multiple clips (Clip001–003), and separate test clips (Clip004) were compared against these reference fingerprints. For Camera A, the test clip produced a strong correlation value of **0.8959** when compared with its corresponding reference fingerprint. Comparisons with Camera B and Camera C produced significantly lower values of **0.0661** and **0.0053**, respectively. A second test using a clip from Camera B showed the highest correlation with the Camera B reference fingerprint (**0.7005**), while comparisons with Camera A and Camera C produced lower values of **0.0470** and **0.0791**. A third test using a clip from Camera C resulted in a strong correlation with the Camera C reference fingerprint (**0.9319**), while comparisons with Camera A and Camera B produced significantly lower values of **0.0050** and **0.0846**. Across all three tests, the correct source camera consistently produced the highest correlation value, while non-source cameras produced substantially lower values. This consistent separation demonstrates that PRNU-based analysis is effective in distinguishing between devices under controlled conditions and supports its use as a reliable method for source camera attribution. These results suggest that correlation values can serve as a reliable indicator for source camera identification when clear separation exists between matching and non-matching devices.

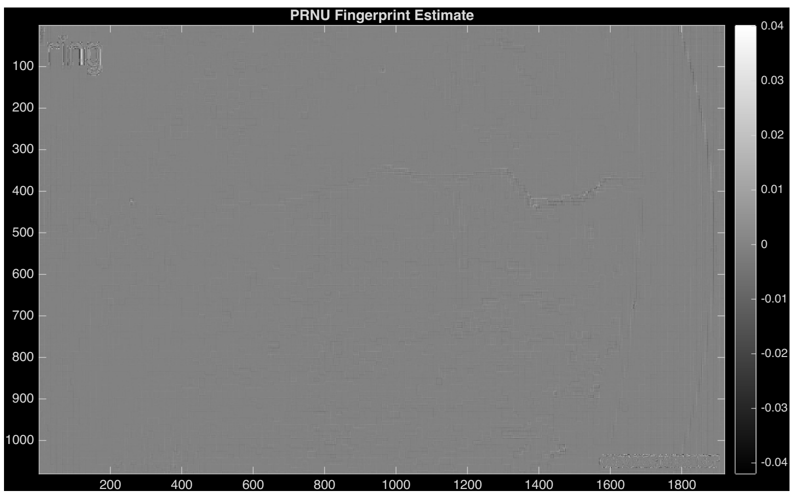

Figure 2. Example PRNU Fingerprint Visualization for Camera A

Table 3. PRNU Correlation Results

Test Clip	CamA	CamB	CamC
CamA Clip004	0.8959	0.0661	0.0053
CamB Clip004	0.0470	0.7005	0.0791
CamC Clip004	0.0050	0.0846	0.9319

Manipulation Results

Manipulation analysis was conducted by comparing original video clips with edited versions created through controlled modifications, including trimming, resizing, and re-encoding. File-level properties were extracted using FFprobe and organized into a comparative table to identify structural differences between original and manipulated files. The trimmed clip showed a reduction in duration from 13.486 seconds to 6.00 seconds, indicating that a portion of the video had been removed. The resized clip displayed a change in resolution from 1920×1080 to 640×360, confirming that the spatial dimensions of the video were altered. The re-encoded clip demonstrated a change in compression behavior and codec format, resulting in a significantly reduced bitrate. These results demonstrate that each manipulation introduced measurable and detectable changes in file-level properties, including duration, resolution, and bitrate. Even when visual differences may not be immediately apparent, structural analysis provides clear indicators that the video has undergone modification. Each manipulated file presented in Table 4 is uniquely identified by its SHA-256 hash in Appendix B, allowing independent verification of the exact files analyzed.

Table 4. Manipulation Analysis Results

File	Manipulation Type	Duration	Bitrate	Resolution	Notes
CAMA_MANIP_001_ORIG	Original	13.486	12870290	1920x1080	Baseline
CAMA_MANIP_001_TRIM	Trimmed	6.00	1109621	1920x1080	Duration reduced
CAMA_MANIP_001_RESIZE	Resized	13.486	216575	640x360	Resolution Changed
CAMA_MANIP_001_H265	Re-encoded	13.486	726149	1920x1080	Codec changed

Combined Insight

The combination of PRNU-based source identification and structural analysis provides a more comprehensive approach to video authentication. While PRNU analysis supports attribution of footage to a specific device, structural and metadata analysis offers insight into whether the video has been altered. Together, these methods strengthen the reliability of digital video evidence by addressing both origin and integrity.

CHAPTER V

CONCLUSIONS

This study shows that PRNU sensor-based analysis can reliably attribute video to its source camera under controlled conditions. High correlation values between each test clip and its matching camera fingerprint—and low values for non-matching devices—support PRNU's effectiveness for source identification. In parallel, common video edits (trimming, resizing, re-encoding) introduced measurable file-level changes (duration, bitrate, resolution, codec) that indicate tampering even when visual differences are not obvious. By combining sensor fingerprinting with structural (file-level) analysis, the forensic framework can both identify the source device and detect editing, strengthening the reliability of consumer video evidence when authenticity and provenance are critical.

Future Research

Future research in PRNU testing should expand this study by incorporating additional camera devices and larger datasets to further evaluate the reliability and consistency of PRNU-based source identification. Increasing the number of test clips per device would allow for more robust statistical analysis and stronger validation of the correlation patterns observed in this study. While the present study used a controlled workflow to evaluate PRNU-based source attribution and manipulation detection under selected processing conditions, future work could broaden the analysis by testing how different software tools and manipulation methods affect PRNU reliability, metadata structure, and source-camera attribution.

Future research should also compare multiple PRNU extraction and analysis algorithms. This study used a wavelet-denoising residual-based PRNU workflow with normalized correlation matching. Future work could compare this approach against other PRNU methods, including

Wiener-filter-based extraction, total-variation denoising, enhanced sensor pattern noise methods, maximum likelihood estimation, feature-based PRNU approaches using higher-order wavelet statistics, and machine-learning-based classification methods. Comparing multiple algorithms would help determine which methods are most robust when applied to compressed consumer surveillance video, especially after common editing, platform-based processing, or transmission.

Further research in manipulation testing should include a broader range of manipulation types. In addition to trimming, resizing, and re-encoding, future studies could examine cropping, frame deletion, frame insertion, splicing, stabilization, sharpening, denoising, brightness adjustment, contrast adjustment, color correction, metadata stripping, container conversion, recompression at different quality levels, and platform-based reprocessing through cloud storage or social media services. Testing these additional manipulations would provide a more realistic understanding of how consumer surveillance footage may be altered before being submitted or entered as evidence.

Future research should also examine how different interpolation algorithms affect manipulation detection and PRNU analysis during resolution-change processing. In the present study, resolution change was performed using FFmpeg's default bicubic interpolation when scaling clips to 640 × 360 pixels. Future studies could compare bicubic interpolation with other scaling methods, such as bilinear interpolation, nearest-neighbor interpolation, Lanczos resampling, and area-based scaling. Comparing these methods would help determine whether different interpolation algorithms alter sensor noise patterns, compression structure, metadata, or correlation values in ways that affect source-camera attribution.

Additionally, future studies should integrate more detailed structural and metadata-based analysis to enhance detection of video manipulation. Expanding this approach to include a wider range of recording conditions, such as varying lighting environments, motion, camera distance, and compression levels, would provide a more comprehensive understanding of how these forensic techniques perform in real-world scenarios.

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APPENDIX

A – FFMPEG AND PRNU PROCESSING COMMANDS

FFmpeg and PRNU Processing Commands

This appendix provides the command-line operations used for video processing and frame extraction, as well as representative MATLAB R2025b Update 5 code used for PRNU fingerprint generation and correlation analysis. These commands are included to support reproducibility of the experimental workflow.

A.1 Frame Extraction Using FFmpeg

The following command was used to extract individual frames from video clips for PRNU analysis:

```
ffmpeg -i CAMA_PRNU_004_ORIG.mp4 frame_%04d.jpg
```

A.2 Video Manipulation Commands

Trim Video (Re-encoded)

```
ffmpeg -i input.mp4 -ss 00:00:02 -to 00:00:08 -c:v libx264 output_trim.mp4
```

Resolution Change (Scaling)

```
ffmpeg -i input.mp4 -vf scale=640:360 output_resize.mp4
```

Re-encoding to H.265

```
ffmpeg -i input.mp4 -c:v libx265 -crf 28 output_h265.mp4
```

A.3 File Property Extraction Using FFprobe

The following command was used to extract structural properties of video files:

```
ffprobe -v error -show_entries
    format=duration,bit_rate:stream=codec_name,width,height,r_frame_rate -of
    default=noprint_wrappers=1 input.mp4
```

A.4 PRNU Fingerprint Generation (MATLAB R2025b)

The following MATLAB script was used to generate PRNU fingerprints from extracted frames:

```
files = dir('*.jpg');

residualSum = [];
validCount = 0;

for k = 1:length(files)
   I = im2double(imread(files(k).name));

   if ndims(I) == 3
      I = mean(I, 3);
   end

   I_denoised = wiener2(I, [3 3]);
   residual = I - I_denoised;

   if isempty(residualSum)
      residualSum = zeros(size(residual));
   end

   residualSum = residualSum + residual;
   validCount = validCount + 1;
end

fingerprint = residualSum / validCount;
```

A.5. PRNU Correlation Calculation (MATLAB)

The following code was used to compute correlation values between test fingerprints and reference fingerprints:

```
corrValue = corr2(testFingerprint, referenceFingerprint);
```

A.6 Ffprobe Output Results

FFprobe Command Used

The following command was used to extract structural and encoding properties from each video file:

ffprobe -v error -show_entries format=duration,bit_rate:stream=codec_name,width,height,r_frame_rate -of default=noprint_wrappers=1 input.mp4

The extracted values were used to compare original and manipulated video files, focusing on differences in duration, bitrate, resolution, codec type, and frame rate.

The following output was generated using FFprobe to extract structural and encoding properties of both original and manipulated video files. This data was used to construct the comparative analysis presented in the Results section.

```
=== ORIGINAL ===
codec_name=h264
width=1920
height=1080
r_frame_rate=426/13
codec_name=aac
r_frame_rate=0/0
duration=13.486000
bit_rate=1280290
=== RESIZE ===
codec_name=h264
width=640
height=360
r_frame_rate=213/13
codec_name=aac
r_frame_rate=0/0
duration=13.486000
bit_rate=216575
```

=== H265 ===

codec_name=hevc

width=1920

height=1080

r_frame_rate=213/13

codec_name=aac

r_frame_rate=0/0

duration=13.486000

bit_rate=726149

=== TRIM ===

codec_name=h264

width=1920

height=1080

r_frame_rate=213/13

codec_name=aac

r_frame_rate=0/0

duration=6.000000

bit_rate=1109621

Appendix B – SHA-256 Hash Manifests and Verification

This appendix contains SHA-256 hash manifests for original exported video files and for derivative working/manipulated files created during this study. Hashing was used to demonstrate file integrity and to provide unique identifiers for each evidence item and derivative throughout the workflow (NIST, 2022; SWGDE, 2018).

d33b8db29769c9710cce78eb4f2a7df09bc12ba5a90affb49cab57422d1da7d7
./Manipulation/CamB/CAMB_MANIP_005_ORIG.mp4
5d18264ca8f4c976b98aac2444c45f2105a5287ac1f060d85457429413dddbe3
./Manipulation/CamB/CAMB_MANIP_004_ORIG.mp4
51341ada823d601b9952b0d8ee4dbf0b2dd24e69cbe31755a00dc580d10b98c6
./Manipulation/CamB/CAMB_MANIP_002_ORIG.mp4
4991ae0389dddf0abefe91169f4b3bec1f774b21b9a197cef12855efcd7202a3
./Manipulation/CamB/CAMB_MANIP_003_ORIG.mp4
fcc94c9b6029763c2edf93058476da3ecc62e38768f6f7970f93e88f167db263
./Manipulation/CamB/CAMB_MANIP_008_ORIG.mp4
e63640ea449d1091928a6456447e9d3dab4060583607e8df8760d0738970dfd5
./Manipulation/CamB/CAMB_MANIP_009_ORIG.mp4
cdd6ae2c370ecd33d4d8d7bf9c75613add85ccea1afcc2fa594621ce577305c9
./Manipulation/CamB/CAMB_MANIP_006_ORIG.mp4
439f2a257f770df9269d1f86a67fcd46d55d9350b43ef018beadf0110759f686
./Manipulation/CamB/CAMB_MANIP_007_ORIG.mp4
6cba02d18220dc9c9d8145594a9fc485675d9be80b2681fac28612a8050103d7
./Manipulation/CamB/CAMB_MANIP_001_ORIG.mp4
89e339110eeae494e91ad5791bbdc7652d890814c051e34ba796424d223d23bc
./Manipulation/CamB/CAMB_MANIP_0010_ORIG.mp4
c49dbb1ab6faebc5579dec263cc943dfa190f92faa62a7b98978fae2bd0a3e8f
./Manipulation/CamA/CAMA_MANIP_004_ORIG.mp4
6078f738cf30d109a70e585580d9bb7bc1ea675273c859add53b37eccad31247
./Manipulation/CamA/CAMA_MANIP_005_ORIG.mp4
255317ba49dca61ae0cf33452a7e3c43a8e47e939598e88808d37ff9f202de23
./Manipulation/CamA/CAMA_MANIP_009_ORIG.mp4
b2a56a657d70f7dab43b99ad18c7730fbdc0335092a11405976bfa44b863968b
./Manipulation/CamA/CAMA_MANIP_008_ORIG.mp4
85f6615f5925ce522f2556d3a7b1035b61ec8c74edf182211da4972b011197d3
./Manipulation/CamA/CAMA_MANIP_003_ORIG.mp4
645f938e11de013ef3129026e88742a142a7082aefb9fabbad309ef6596a14ee
./Manipulation/CamA/CAMA_MANIP_002_ORIG.mp4
09f332a7d4018f08fd51d0049f23e6d51b867f9f1f3d6405ee02c140c0f7db1b
./Manipulation/CamA/CAMA_MANIP_007_ORIG.mp4
18e10c910c50aea74c5a9d82cb3823b8817af1b0b45ef8476ab6436be6f8738a
./Manipulation/CamA/CAMA_MANIP_006_ORIG.mp4
7c68243eaa51c1fa02fc97309eaaf45b4a2c2f1639de67b8b35d02088430adf3
./Manipulation/CamA/CAMA_MANIP_0010_ORIG.mp4
a90413056a387a43d54e1bae15b255257c52759dcad4e10b414d9325d90f75ac
./Manipulation/CamA/CAMA_MANIP_001_ORIG.mp4
812ae45a0d0ce54a6e9d15db273483930a511755dedfc0cbb2c3d2f2669d992f
./PRNU/CamB/CAMB_PRNU_007_ORIG.mp4
1761a3a8878de75697591635b754b599a5e7e13bc954bfc15ab260770ecac52e
./PRNU/CamB/CAMB_PRNU_006_ORIG.mp4
2439ab20041d5def66f8fd2129aa605f84d493880db78a0460e080d47dbebcff
./PRNU/CamB/CAMB_PRNU_0010_ORIG.mp4

ab841eb4694434bb17019277dc855af0afb180c572e7c5e7bf6449f7d5b914e7
./PRNU/CamB/CAMB_PRNU_0011_ORIG.mp4
e54a8ecb99bd160a22e567f12a4591184a266b4695a2bba248cd37d1bfeca236
./PRNU/CamB/CAMB_PRNU_001_ORIG.mp4
8e89739f96ffd0976a2dbd2ee541554a24f9a4039ab90f276450c8801977d4f7
./PRNU/CamB/CAMB_PRNU_0013_ORIG.mp4
a93f7c25a6326b2a0522f6cc72112a3a3393c13f1478433a10fbaf6b3cd33eee
./PRNU/CamB/CAMB_PRNU_0012_ORIG.mp4
af409c198e5a8a4a124c5fdd6bba9ef6f97d250b5874f753ad366e8df6fba1a4
./PRNU/CamB/CAMB_PRNU_004_ORIG.mp4
90bb216a1c67e985df0201433f84e82782279baeb7d760a8b2f25573cf9e291f
./PRNU/CamB/CAMB_PRNU_005_ORIG.mp4
8bfc43dfd77d34bd2789c4b8fd052b337db302d32267ed5b3e0306309d486e85
./PRNU/CamB/CAMB_PRNU_009_ORIG.mp4
6e155c6b844906eb509e9cf80829aeb3806951431a75b594ebf958d3a596a0c8
./PRNU/CamB/CAMB_PRNU_008_ORIG.mp4
e9c775059bb18df005728e2c428eb4f86e35bd85f9f9354c9bac2da84946afc5
./PRNU/CamB/CAMB_PRNU_003_ORIG.mp4
16586e1df0984c528f156d8fd424ebfccb8f1cc760ab81d8e0b195c78b4b10f8
./PRNU/CamB/CAMB_PRNU_002_ORIG.mp4
524c39203d3410fe81a3cdcf7e464226fd98e561ff2f8b46ec3348050c7f8a04
./PRNU/CamB/CAMB_PRNU_0014_ORIG.mp4
12c3e559fc8f51e3caac690b4f7b4b6e327cf10f2ea841fcaf2d4349a7398921
./PRNU/CamB/CAMB_PRNU_0015_ORIG.mp4
d1aa83adf3cdcbdcf0121f24d0b0784e34766dd155b9800f46d0b7af037fb729
./PRNU/CamA/CAMA_PRNU_001_ORIG.mp4
caed545deb52f05de680756029ad7e434e33ed3be07c5ef15a98c06a306ff263
./PRNU/CamA/CAMA_PRNU_0011_ORIG.mp4
4c8ae58e9bb5f917f7d690408349fb2f5813b83f80b9716b53db0029abf70ff9
./PRNU/CamA/CAMA_PRNU_0010_ORIG.mp4
8d0f43b8077dc0f29034ea9edca2e39857d7b0cf825816cd17a79dcd3394b345
./PRNU/CamA/CAMA_PRNU_007_ORIG.mp4
4bdf9833c6a7c6203278cc3c3f02bbac89d5dc87295aacb2bed2c28f7d50d841
./PRNU/CamA/CAMA_PRNU_006_ORIG.mp4
054cd4c4c4b3802956f1f236a10208bb38623d0a4ec401de90483f639c7e009a
./PRNU/CamA/CAMA_PRNU_0012_ORIG.mp4
353df990c0ffdd65ed3aca622a4322f0e23c9ac9054523442f7101b8350bd979
./PRNU/CamA/CAMA_PRNU_009_ORIG.mp4
ebeb3dfa2cff8ad9ec45b0c0c6169c6fe034df05b3ca164ffbd3bfb3790b530d
./PRNU/CamA/CAMA_PRNU_008_ORIG.mp4
1ee6a21cd8d74ca0377e985746409f7e78f7fe784477b5f0dc3435226ed6a95d
./PRNU/CamA/CAMA_PRNU_0013_ORIG.mp4
13b9fe41705af76cf2d107533fddf28f51ca598f488b8b84b8b94af810d3b39b
./PRNU/CamA/CAMA_PRNU_003_ORIG.mp4
474f98f54d0bdf107221b9092cf4f7f735f70747d1e98e3617e4aa9fd1f7687e
./PRNU/CamA/CAMA_PRNU_002_ORIG.mp4

9d719e2a01a8177e6a3d5570a66b79aa61eb2dc4a4aa8d547b995d67a02dddca
./PRNU/CamA/CAMA_PRNU_0015_ORIG.mp4
185456aa8455d6aa15316120e4d505e26e2132163f0b9001c810f8c4e5bfeedb
./PRNU/CamA/CAMA_PRNU_0014_ORIG.mp4
6af3d16dd53a847083d7b24f0956219bd941a7e1f0f7234c524eabf8ed099e9f
./PRNU/CamA/CAMA_PRNU_004_ORIG.mp4
1ee4cd097bc2a48607d3ea4f9a2fa575ed7ccd5cc72a21806caac9544683d449
./PRNU/CamA/CAMA_PRNU_005_ORIG.mp4

Appendix C – SHA-256 Manipulations

d7cd65bc66afceab863c83b131df114ca675d5c7e2dc808ac7c6d3eb697c35a4
./CamA/CAMA_MANIP_001_FPS15.mp4
3a07d6133d88daf7a109fddeba8073fca9e619f0ff294fa4feeb454b42b53ad9
./CamA/CAMA_MANIP_001_LOWBIT.mp4
a3cdf4f975cbe82b67f20f983645266a7c9ab2dfc5d40ac9c143d3689418e352
./CamA/CAMA_MANIP_001_TRIM.mp4
d342eb8cd14da2ee7c8933aa7e07845b13b48eb64cae61b905edd777004fc4ed
./CamA/CAMA_MANIP_001_REENC.mp4
913220426d304d9bc1f17cc22be31193502b042fea94648d64c4fcf9b4bc2122
./CamA/CAMA_MANIP_001_RESIZE.mp4
9f0e1baf00bdf0545faa15ed5e4894756aa0a3f0df298dd283b507daabd43954
./CamA/CAMA_MANIP_001_H265.mp4

Appendix D – SHA-256 PRNU Outputs

This appendix provides cryptographic hash values for selected outputs generated during the PRNU analysis process. These outputs include reference fingerprint patterns and key processed data used in source camera identification.

Due to the large volume of intermediate data generated during PRNU processing, only final reference patterns and representative analytical outputs are included. All files were hashed using the SHA-256 algorithm to ensure reproducibility and integrity of the analysis.

Appendix E – Stream Hash Verification Command

ffmpeg -i "filename.mp4" -map 0:v:0 -c copy -f hash -hash SHA256 –

fFILE: ./01_Originals/Manipulation/CamB/CAMB_MANIP_005_ORIG.mp4
0,v,SHA256=80a94aa20ad42235e2ef92e7279eea30ac3cfb8812538599047a0a26b08ecdd0
1,a,SHA256=c209a222d44b8b79c0eb57bca026164856c85bb41d32887e968cb652015e8f65

FILE: ./01_Originals/Manipulation/CamB/CAMB_MANIP_004_ORIG.mp4
0,v,SHA256=d792e3ab600a1d7825eb7f92c280b84f6a9b32c3c3848df047fde701d020dde2
1,a,SHA256=2271d16acc065598e9875cd86c85537f95bd648263c5dc9ff5053a8f958e746f

FILE: ./01_Originals/Manipulation/CamB/CAMB_MANIP_002_ORIG.mp4
0,v,SHA256=a5195b1ad2752347a53a05eaddc4f2c1041bfc8611d7a683c2bad86670b51ea5
1,a,SHA256=92a4b95bdcf4d7fe2f843a73b4af68c486d8e8d232faf63cb0bde0e91e0b0fe5

FILE: ./01_Originals/Manipulation/CamB/CAMB_MANIP_003_ORIG.mp4
0,v,SHA256=2efc3c5f23be38bcaff112fb02574616eff5a1baaeaadd8ddaae18ba59ed7844
1,a,SHA256=a3eb83686dbca4b62435d0eee15bae294dbdde618b0861684e844adddfbf4138

FILE: ./01_Originals/Manipulation/CamB/CAMB_MANIP_008_ORIG.mp4
0,v,SHA256=63b8dcce37dfedec25133d36a2bcf14f7399b333c4a0cb1705e545efcc67470e
1,a,SHA256=a2e8a273bc49fa84595a1f0508a34fd91192fab45be65450a08ebdc1df05c73e

FILE: ./01_Originals/Manipulation/CamB/CAMB_MANIP_009_ORIG.mp4
0,v,SHA256=85e880fd84599eecf18b61e62be77bffc7067f8a341017fa3f1f19006e61d9ba
1,a,SHA256=534c807ae3ff72cf3cc69791165e88a6d2dd6abcc7dae8921e1e4c8014c1157f

FILE: ./01_Originals/Manipulation/CamB/CAMB_MANIP_006_ORIG.mp4
0,v,SHA256=ad7886575a052f2f21d07d726e57a32f0c6d6c36cebfb222369072c7d9355e67
1,a,SHA256=fba8ba5421d78d15e628c90477321e4578faed38fa6ca67c3f1bf3d5de961c4a

FILE: ./01_Originals/Manipulation/CamB/CAMB_MANIP_007_ORIG.mp4
0,v,SHA256=4afe1c8eca01054b3605d882d1650833247a027cde29d6b91dde8fefe3ec9f50
1,a,SHA256=778c0f5041c6161e77937f1ed96d4f3855ae1a645be836bf85984c55dd7d0820

FILE: ./01_Originals/Manipulation/CamB/CAMB_MANIP_001_ORIG.mp4
0,v,SHA256=563806fcbe3af87e57db165dc81a713e6c8ebb259f87d2eae4fdbfa7546135ba
1,a,SHA256=4cceb98e9245f7d98d55b1f9830210bfb8c3a06365fd1d909acb24a6c7e51ab3

FILE: ./01_Originals/Manipulation/CamB/CAMB_MANIP_0010_ORIG.mp4
0,v,SHA256=5d2fd7116750f88b4c89cc0088180da475a2cc2e80df8f9112a3e3860879b16b
1,a,SHA256=659d9d6b4ae4962919a0fb352eb6e9c746ed43683712cd2f1692c885e698891f

FILE: ./01_Originals/Manipulation/CamC/CAMC_MANIP_001_ORIG.MP4
0,v,SHA256=86badc322cbc571330f84ffdbf33857f460f58c4e822f85978740ec4853f9849
1,a,SHA256=778221767145849f522599d8a588caff27fc3dbcd73460bc8a0927ae2f5ea131

FILE: ./01_Originals/Manipulation/CamC/CAMC_MANIP_006_ORIG.MP4
0,v,SHA256=f65c17953266c5e6dcb4138b1fbe19c682f12a3aad1d885273377b133662edd5
1,a,SHA256=1f0f2be0cc58a84b2a56fe90edc3df3fdc9e0f6b796f97e726cd31c868f540e3

FILE: ./01_Originals/Manipulation/CamC/CAMC_MANIP_007_ORIG.MP4
0,v,SHA256=36262d77c027d3a8687e8fa5571dd92f1a8e9458850f4d581c20b2fec7b8ba8a

1,a,SHA256=bad072bf59b11742079281c41409829dc1a0f2e9c9863127c0bf7ed8e2524624

FILE: ./01_Originals/Manipulation/CamC/CAMC_MANIP_002_ORIG.MP4
0,v,SHA256=7b6d87d00eb99f46704aa0ce358228529cd0966636793d3daede0c6433a89a58
1,a,SHA256=4ae125954d5c3d0e3a994701d1134ef7e78572065cae92c8bc253763679615d4

FILE: ./01_Originals/Manipulation/CamC/CAMC_MANIP_003_ORIG.MP4
0,v,SHA256=be8ca9e1d8f069a2d70712109fff43364ddb9eeacbbace3cf6968c933783dae8
1,a,SHA256=1e75bc2f222d19f19e7a046206f0d37c9f555ee694f9d4ed2891dba6bca2816f

FILE: ./01_Originals/Manipulation/CamC/CAMC_MANIP_008_ORIG.MP4
0,v,SHA256=d17d8fcc8978662088c7924821d7903d861d119303997ba175817ce4ef21ad70
1,a,SHA256=0636d781c8f0bc256a9e8dc2b14ffc9759d9b1380942842e4c7700ef7b0d81c5

FILE: ./01_Originals/Manipulation/CamC/CAMC_MANIP_009_ORIG.MP4
0,v,SHA256=1a187b735902da8521746fb5538705044a543642064aa025ba34c59be0710b22
1,a,SHA256=ba694daf7f30d5cc95e41eb8c7af9824c07ec99cbf1e2bcc54dc77c6b66c008e

FILE: ./01_Originals/Manipulation/CamC/CAMC_MANIP_005_ORIG.MP4
0,v,SHA256=8005ecf6e9375741d10c66ff15b6811f8eeb5387f10113f2f59b3797685a367c
1,a,SHA256=9d4a07e0dafd385c6d09989eecb0a4c283b9eae2658b3eaeb85291b54d0a3b97

FILE: ./01_Originals/Manipulation/CamC/CAMC_MANIP_004_ORIG.MP4
0,v,SHA256=af0c50d7f22c38199f167eb36ed768cf443321fab264a0af13d622f70a53e610
1,a,SHA256=24b3e646ab4f53bc85a08a460028f140932ef4ccbbf95d08ceb9748ad774f01a

FILE: ./01_Originals/Manipulation/CamC/CAMC_MANIP_0010_ORIG.MP4
0,v,SHA256=3b6cac7ef09614078dda03226cb707502ab6d832625d2e460dcca29b1a55d407
1,a,SHA256=ffbf4837cd87c55a0f0c006ee982fd6701e7cc658974f5a386365620dc699a0a

FILE: ./01_Originals/Manipulation/CamA/CAMA_MANIP_004_ORIG.mp4
0,v,SHA256=a9ae29c37b07635b1826f79b54532867860d60f12c7141737d34acd0c1754b89
1,a,SHA256=de8f26500dac95d5e55024fbd4792a93b109d3dc1e2b2798822b640e12972b56

FILE: ./01_Originals/Manipulation/CamA/CAMA_MANIP_005_ORIG.mp4
0,v,SHA256=7c2a4942a33dc8686e53fa226504adae1e1cf5c7c722785c5bc85812a6620658
1,a,SHA256=d2c33a1c4200b20aa09f7472bfdd62af2109d0eb1c58a664b635e1bae3214fce

FILE: ./01_Originals/Manipulation/CamA/CAMA_MANIP_009_ORIG.mp4
0,v,SHA256=5e38182f403d9ccb6319ca3da5f8fcb40ce5dc0217036855e6633f4c494370ae
1,a,SHA256=39da3a097fd527a4028e0de47e5b41705a9f03069c3f5b884d1c7183b59b8b28

FILE: ./01_Originals/Manipulation/CamA/CAMA_MANIP_008_ORIG.mp4
0,v,SHA256=4bcf87cc370004ecd6ca7f2451dddb33ebd0c7afe978a8df2082a3806de8f663
1,a,SHA256=56a418bf0e280fbd6bb5ecfc0de0949433692cca20709e0e6bd6757447d1713f

FILE: ./01_Originals/Manipulation/CamA/CAMA_MANIP_003_ORIG.mp4
0,v,SHA256=d3abc845fd4be8cc457c4fae0225a4175eac9227ec98f590b5f99688c994f05f
1,a,SHA256=3278e015fd461917e5c67b9149d423af07fae8ff849549c41745639f1a22b215

FILE: ./01_Originals/Manipulation/CamA/CAMA_MANIP_002_ORIG.mp4
0,v,SHA256=4bad78319d590784118d05e6a2e1d3880d92c1be8426fb30b13ac215e105fa42
1,a,SHA256=315a2f8f8540ef4308ec8ea7cc1656b1f46b9b3847b12e8ecec55a78c589f8b0

FILE: ./01_Originals/Manipulation/CamA/CAMA_MANIP_007_ORIG.mp4
0,v,SHA256=06e65106b38ec2cb3c2e8e4052e6e7bee01b4ead1f51c4e137c9bbf84e32b41a
1,a,SHA256=4e46b3dc82b4116900d6612defc4e4457b0750381a57feb684a2ee3f1db8fa98

FILE: ./01_Originals/Manipulation/CamA/CAMA_MANIP_006_ORIG.mp4
0,v,SHA256=ccce5427ef5bc67324037dbfdd51128a90cc249de8b63700017048dc4556a473
1,a,SHA256=6a0e447d34dfa9adbe709bc73d75e072c47ebd8b68752e277f66ca2fc97f64c0

FILE: ./01_Originals/Manipulation/CamA/CAMA_MANIP_0010_ORIG.mp4
0,v,SHA256=9e51440fc25246025f0478e0d90fd9891bd6157c6606499f61d63234cdaeadb0
1,a,SHA256=06e1b72fdc04fc19acc7051e36eb3b5691e19c619430e247ff09023ee635ccb2

FILE: ./01_Originals/Manipulation/CamA/CAMA_MANIP_001_ORIG.mp4
0,v,SHA256=8390c3fcec0d46bb4310e403a98ba8074408d57222ab1a9f7bd92ddcc2775e88
1,a,SHA256=760699bb8c6ace6790320750195079b67fb52edf95c0e39a6d334c3410ae84f0

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_007_ORIG.mp4
0,v,SHA256=69c6322197c5d05281731e75ac369c4d9adfe37502fa99cb7e6b181dbbbc233d
1,a,SHA256=01abf9afc8a34c56228219f1f57b71a95a1cb4fbb749bb6bb4abf6a2d4769623

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_006_ORIG.mp4
0,v,SHA256=faa9d83c6ce5cd6a51d22b5e1f5c33dac3aded29db4c2a52e1bff32664c3381a
1,a,SHA256=200d40917439bc817b7db8681800ea6949611ccb2e6632f365dc319e1c784ae5

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_0010_ORIG.mp4
0,v,SHA256=ae97f73de65dc7d2210eb2b9e03b890ee950aa8e213306ea992e7889ec539bcd
1,a,SHA256=f2105c8da674101b0c72dd8916bdae90596bfcb0b80014b38ae96731973b993b

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_0011_ORIG.mp4
0,v,SHA256=f510a85b6bf1ba77a1a2675426bf811f44e43d513525a01b5fc1a9008f5c4df7
1,a,SHA256=14ecd260df0fdac8dbb4cd0937f63bc4527d11a676d2fd083461fe735a40dde2

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_001_ORIG.mp4
0,v,SHA256=5614677ee2ed8a24f37e9b3cc191efdbd882bca8db55672510fc7154f6339dda
1,a,SHA256=de2e8fd5d20ef2bd8387396e6ebe6254cc1fadd8ebafebf007cd107ecaf71f50

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_0013_ORIG.mp4
0,v,SHA256=f9c4ee8d6faf015c7e4a7db9d36ed913529857abf9ef1fb652546baa14ad23b8

1,a,SHA256=489025458f7d581c93eb72f334c0cbac3266e0abaddd210e92bd4514a501dd8f

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_0012_ORIG.mp4
0,v,SHA256=50210574a9e803bbec36c0ac6d68646bafaf706bebf9ebf88f8a9ff56c369303
1,a,SHA256=1d19be159ce77f9f88c750e40d01834fb0469661d3eda9b5ee7083953d862c20

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_004_ORIG.mp4
0,v,SHA256=0f64f6ff091defce7678cd89371383a6fd9fcf5e7a03cc57787b8246b164c2f8
1,a,SHA256=2eb32849e6bd9f179c50c5df8bf2ffc20806718c50361fc68e464e5c7991132d

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_005_ORIG.mp4
0,v,SHA256=3a34180cb434826978df9207628e773babf7fab53f7ce5406be5620da0374fae
1,a,SHA256=aa683591bd5ece9ba82215f745f865f86244256beb357dac518ec60775157968

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_009_ORIG.mp4
0,v,SHA256=3bd1d26635dbb27fd95bf720109970c69fdda2392f8144e7d014a03b6d126874
1,a,SHA256=a8586c91b6f52bdd441d211001307a2b60a2ab848c16cfd2e545b33b09371162

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_008_ORIG.mp4
0,v,SHA256=37e23adf9b16a53a8746cb52171ae6bb4e4d34e9b1a2744975282189ea7515fd
1,a,SHA256=d313d6143c3cca065cc7cd319ddfade40c18f1700ce8988ec9aa3ef44e8d5571

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_003_ORIG.mp4
0,v,SHA256=794116c676b282f909e7b0141623bd0aee619794fc3975a1dfef7718abe2b2ee
1,a,SHA256=3f12a0e4d3605f9cfcd2a9b74d76fd8e202285e0a003d605628fe585c51f47c6

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_002_ORIG.mp4
0,v,SHA256=7aefe815f015b44112dfd24c06a771f3dad51a896e2127a970b6628cffbdab33
1,a,SHA256=e7dd81bb1dd0fcea269c3ed10fffbad921c0cf75acc611a4ae51531f991d50d3

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_0014_ORIG.mp4
0,v,SHA256=55cc63fdeb470ff337752c0406f1365976d73d85dead692dc739acde5ef5123b
1,a,SHA256=51a7057dc1678c6712c4362a808817f3ce0cc40077b965b4408101cfa2305a1d

FILE: ./01_Originals/PRNU/CamB/CAMB_PRNU_0015_ORIG.mp4
0,v,SHA256=55074e6229835c1b2f38949e4461ef14f604cc818b232522e378d9a5d09318e7
1,a,SHA256=0d15cfcb3764ee65e96a02e9c40c25b470f5271568a8993613710a330144e7e6

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_0014_ORIG.MP4
0,v,SHA256=dfa98c724b6a51a8bed1dd855a6d1b0ef105e736325fa1398b849b75b1e0c87a
1,a,SHA256=26099265ecca68ffdf4ef0e4850a6c3a38f20cda33778333f3e73404c05f5b11

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_0015_ORIG.MP4
0,v,SHA256=5cba73c1da765328e9a48944856088c8cab150b3e0eae2456d14b09577eb38bd
1,a,SHA256=62cfc1ecb313c4f81e4a02f97bef855c309123ec375f338e72c682e0344c0a68

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_006_ORIG.MP4
0,v,SHA256=36aaa0fbb43cf39079e9f208aa1a1d7d66d3b2caaaff068c0056eb4d6e1bd800
1,a,SHA256=a66c4eaf29df3c02ff4b0e012c316ff12434affe039c8891f6c4bd16bb4154dd

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_007_ORIG.MP4
0,v,SHA256=2cfe659722945d97cb3912ff1b383f01a63601d160fc886b866b2968d5aa10ee
1,a,SHA256=5d8da70f155e44408b95840d15e35a960cd750a092150e5ea68f96172288c357

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_001_ORIG.MP4
0,v,SHA256=2aceff934b76ba3ff9b3a271d166dd8cdc995457fdcf707e4a24fa33c26513b0
1,a,SHA256=921009381d3cc7fb647c3b42205a74f076c081b15e2800a6016274bc58761720

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_0013_ORIG.MP4
0,v,SHA256=034ec1b39f2e9f0878fac379925e4358e7536e965ccc74015bad37a36e9409a6
1,a,SHA256=eb148170c7cac676142daed50e6bffb47681e75d5523add9ce3c5134b0ec4cb0

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_0012_ORIG.MP4
0,v,SHA256=b5e972979e773cf1fb2c1b0a4a507465cf54fe54ae79f547e23229c8da52435d
1,a,SHA256=8f1898449b594643abe68f404d8c4ba393342e2403749bb9adb1ce90ea27317e

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_005_ORIG.MP4
0,v,SHA256=5f2518061f12fa651833e84e7211175f7ecc293b7b434ffd962ba1beabf10cd6
1,a,SHA256=d6198ce059d29e8c963e1ab23aaf3c41cc259654f8f00525b52535748f828c9d

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_004_ORIG.MP4
0,v,SHA256=8a5c65028696a45f8be54cecdb4246fba774782d4d9051be3d2d9035a28838f3
1,a,SHA256=8dc98a2f982492f879ae0da9e8900c01577d46e2c094ac7fecfc19ea84c67dfd

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_0010_ORIG.MP4
0,v,SHA256=748655c255c83479cebd6622098bc6947fa964f4a1e8d06b04c556d18cb14ce7
1,a,SHA256=5461aa1bde3a7d4d043711b7a00c17a11d0b74292ddff52f585f2a602a49e3b9

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_0011_ORIG.MP4
0,v,SHA256=8a58ff94893f5c8ab80ce670c2684e361332d6960555e97cd754de3de1744ab3
1,a,SHA256=ac192b8afbcbf0b009db14899e829fa90adb67399db8ad5b5783e67bcb4d9434

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_008_ORIG.MP4
0,v,SHA256=60af8fd7ec19301537a0df33d528ccb63dee50532e8d2a67dafa0baa68150234
1,a,SHA256=7067b381a988f8b2cc586e592b7a0cc4b95837f5becd25c8f76e40bdf765459f

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_009_ORIG.MP4
0,v,SHA256=68d31aca603433253c318b37479dc31325c698affed76e18af1487be4712c9ce
1,a,SHA256=3d5d98b3bac446a09d950422a2f8602c5024af4e98580133d3c0a29c4e57da8d

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_002_ORIG.MP4
0,v,SHA256=074d011516a89174ccca8902138a00cc39b08bb0e6bc8165ba266eccdd459ba0

1,a,SHA256=08023e760a9c7d66d1231b66260e4f8e3aed081d712a147fa0dabb4340358432

FILE: ./01_Originals/PRNU/CamC/CAMC_PRNU_003_ORIG.MP4
0,v,SHA256=9637e3c0c0f305ef61daf260b67fbe48b4ece88d223bc1c9e2609d3ecb36737a
1,a,SHA256=d820f75331a1375eac1041b4cabffe54468bd72bfb4b6a73ac17dc25996ea644

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_001_ORIG.mp4
0,v,SHA256=daa068cba8ff70f8710a01ca1ee61bbeb214af2329473e20d34cd92b8f0bc1d1
1,a,SHA256=5d0ff5f4344694c73471697c1933ed150d3fbeae261a69f0e314107fabcdc7cb

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_0011_ORIG.mp4
0,v,SHA256=7eae7d2a155e642c737a0cf99bf087e0493c381ded7d79a002303e83fe9d197a
1,a,SHA256=ddc9db188be8213bdab778905617acb853193113f2d60a8aaf8b5d9e25de8327

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_0010_ORIG.mp4
0,v,SHA256=a277328bd03cd468c4fd6d2b188b917ceb099d8493a412f921033edd9dbe3935
1,a,SHA256=98374a8442e844a66d2713e73db27d13966ca1de12a2d05f5c0e602f8a7370b7

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_007_ORIG.mp4
0,v,SHA256=fc45be1e86e432d9494bec34ce8105cee1da259cf59da1e8c96a1efc4daced37
1,a,SHA256=854ebfedd472716bbc0fa9cb1beb61b15bc8bdb7686aee255c1a317450019222

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_006_ORIG.mp4
0,v,SHA256=f8c4be3cf7b2e29331b0a7e6b97b2e518afad1cd9a5c630118b8832ad9407d0a
1,a,SHA256=22907abe774ef498a8a2f5ad6eb6419d204153cad9fb90baca393d33a921b025

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_0012_ORIG.mp4
0,v,SHA256=9207da12a516f87cdfe70509f7a3fa142ee41d19beeb998bffc90b31b688d3cd
1,a,SHA256=e1ab488ec1375cfa725bc69f8aa6fbc2ccef6bdc53e21f15baa6ab0dce5f2888

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_009_ORIG.mp4
0,v,SHA256=63bbb626b155a94fe52ea87a51e7ba23e52b455715d2ac3ac71e531d3409f2b8
1,a,SHA256=f1c462c2973478bc51f5fc14302230f50fe89b46d6eea4fe0adf4f5c6d5f91f5

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_008_ORIG.mp4
0,v,SHA256=57da3fdcfeaad0b0b89f97101692bb6c41c632883dbd580399ff2b913cadaa5e
1,a,SHA256=a4b2bf51e28b8ebbe453770002173f3b607b4f87d681071802fdcba08d7adf2d

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_0013_ORIG.mp4
0,v,SHA256=e5020b78e8c9afcb5ba6d335c5c4beeadc13e6edceb1f57efdd6470bf74aba1e
1,a,SHA256=0bc3a5d884df4dd91b8616c5524d303fbac9f288372c78e2bf50ed42898cdabc

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_003_ORIG.mp4
0,v,SHA256=e41af0a8c6fb514ef706fb4afec1f526b0d8c1632ae28a42b223ef7fae429451
1,a,SHA256=88131b4b7430a0fedcc465035a18cca0de39ad995e5c3a9d7c342937258b76b5

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_002_ORIG.mp4
0,v,SHA256=cd9212b40475c628be27d08146510256e2e7e70dce87b4b8d86cba72bb1a9667
1,a,SHA256=a10ed84b149adad0e530e83b7e72a73042914047b0c038482adfb3fe87b5a047

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_0015_ORIG.mp4
0,v,SHA256=5e7f7b258a08b9afb347e1e8c718c8080e8f6b0f51064c7d81e003cfbfeb6a76
1,a,SHA256=36facee5ef211eba49dbc9d818f29d9218adbff2c09ca34fed3c8046e70a8317

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_0014_ORIG.mp4
0,v,SHA256=539b1b1dea6536d8d8f68b82f8b837af48b5afa62b007b4c58f247b3e75f8b7d
1,a,SHA256=8b9334c69f5462b725243b7e740bad0107760f0066ad83c6ebf72cf33cbaf63c

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_004_ORIG.mp4
0,v,SHA256=b4b0b2c8648e5e3de073b06272b4b65bced9bc3e3e29748ab8fdb40c695cb0be
1,a,SHA256=949c169ad0af4633fb5fb445ad0b57bd895ec058d77c21a5347573993794a88c

FILE: ./01_Originals/PRNU/CamA/CAMA_PRNU_005_ORIG.mp4
0,v,SHA256=a7fc2e241dfb7ec8a78499e2486b960687091b51ebc6497a2939ceb839b7a32d
1,a,SHA256=ccf406465cbbebe0961307d5674b4aa7dd71538fa4ebd5bc70f8eb825d8a0937

FILE: ./03_Derivatives/Manipulated/CamA/CAMA_MANIP_001_FPS15.mp4
0,v,SHA256=160ec06fb82db024f56b9d496876588736a99849c1480b795048abb7b9bbd002
1,a,SHA256=72ec0c092070350b9f78af82ab23ad220ed1161a9b75a8bbe246d1c4e2302524

FILE: ./03_Derivatives/Manipulated/CamA/CAMA_MANIP_001_LOWBIT.mp4
0,v,SHA256=5cdb3b23e5f6baa3c2157aad8bdc18f511204140daa02d61a61293870e2db27d
1,a,SHA256=72ec0c092070350b9f78af82ab23ad220ed1161a9b75a8bbe246d1c4e2302524

FILE: ./03_Derivatives/Manipulated/CamA/CAMA_MANIP_001_TRIM.mp4
0,v,SHA256=36785ddc9bc840e6d9300dc0f67ea75b546b6a7cd0f26843ed64b7353375940e
1,a,SHA256=cde381b045079ef08fff517bfdb033fcf6c9abeb31371a2e3adf4099dca51842

FILE: ./03_Derivatives/Manipulated/CamA/CAMA_MANIP_001_REENC.mp4
0,v,SHA256=760c90c467686949dabc65581c865e03fb7f94f234d330eb3fea63a7f0d33b90
1,a,SHA256=72ec0c092070350b9f78af82ab23ad220ed1161a9b75a8bbe246d1c4e2302524

FILE: ./03_Derivatives/Manipulated/CamA/CAMA_MANIP_001_RESIZE.mp4
0,v,SHA256=ebf92070f588440a9d55d5f7a1011e990a85c3db2ef89cdb06c80dc311a1c8db
1,a,SHA256=72ec0c092070350b9f78af82ab23ad220ed1161a9b75a8bbe246d1c4e2302524

FILE: ./03_Derivatives/Manipulated/CamA/CAMA_MANIP_001_H265.mp4
0,v,SHA256=811f3a8a7f91c7c36a4992c8a1b891f271623064091eede71bbe2fa6983d4854
1,a,SHA256=72ec0c092070350b9f78af82ab23ad220ed1161a9b75a8bbe246d1c4e2302524