ANALYSIS OF 360 VIDEO FILES ACROSS MULTIPLE RESOLUTIONS AND CAMERAS

by

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Analysis of 360 Video Files Across Multiple Resolutions and Cameras

Thesis directed by Associate Professor Catalin Grigoras

ABSTRACT

Forensic experts rely on the validity and reliability of data consistent with Daubert standards and Federal rules of evidence for identifying findings and formulating opinions about evidence in legal proceedings. Digital forensic experts have an acute awareness of possible distortions or manipulations of electronically recorded or transmitted data. A critical aspect of analyzing digital evidence is to inspect the reliability, absence of, degradation, or alteration of data used in forensic evaluation. New recording devices are constantly being developed. One such new tool is the 360 video available for GoPro players and, often, for broadcast on YouTube. 360 video provides an opportunity to capture, record, and review multi-dimensional digital information. For this study, several test patterns are analyzed using the 360 video process. The purpose of the research is to identify any potential degradation, distortion, manipulation, or data loss when 360 evidence is transferred from an originating device to a secondary device.

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

Approved: Catalin Grigoras

This thesis is dedicated to my entire family. Thank you to my father who, when I was at an early age, showed me the world of forensic sciences and to my mom whose patience is unheard of.

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Thank you to Jeff and Catalin for allowing me to “cd” from the directory of recording arts and into the world of digital forensics. The information I gathered while in this Master’s program is incredible and extremely relevant. I am looking forward to continuing this educational journey and learning more.

Jeff, thank you for allowing me to work in the lab and on the DARPA project. Hopefully, all the work that we have done and continue to do will help many people.

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INTRODUCTION

Problem Statement

360 video has become an increasingly popular multidimensional recording device, yet the 360 technology has not been subject to a thorough analysis concerning its reliability with data transfer. For the technology to meet one of the basic Daubert standards, 360 video requires testing and assessment of its consistency following transfer from the originating device to other media. Without such an analysis, the 360 video technology might not be considered acceptable forensic evidence under Daubert standards, which require the demonstrated validity and reliability of assessment tools.

Literature Review

Over the past two decades, advances in technology have created significant opportunities for and challenges to the collection and analysis of digital evidence for both solving crimes and preparing cases for court. In a white paper prepared for the National Institute of Justice, Goodison, Davis, and Jackson (2015) provided an overview of digital evidence in the criminal justice system. They underscored major themes, including that, "Documentation of digital evidence incorporates the twin issues of authentication and chain of custody." They also cited the growing importance of video evidence in criminal investigations.

Inherent to the growing importance of digital evidence is adherence to rules of evidence and case law. Testimony by expert witnesses (Federal Rules of Evidence, 702) requires that the presentation of data meets standards of adequate reliability and validity to be considered as a basis for the findings and opinions provided by an expert. The courts have moved from a general acceptance standard, in Frye vs. US, 293F. 1013 (1923), to a scientific standard, as defined in Daubert vs. Merrell Dow Pharmaceuticals, 509 US 579 (1993). New technology, then, requires the development of research that supports these Federal standards and withstands scientific scrutiny. In the development of video evidence, data should both be recorded accurately and, in the chain of evidence, accurately transferred from one media device to another. Data transmission is the process of transferring data between two or more digital devices, and such transmission may involve either serial or parallel transfers (Melton, 2016). Robinson (2012) has identified some of the problems that can be encountered in data transmission. Others (e.g., Natarjan, 2003; Tsun-Li, 2014;) have addressed the manner by which these transfer problems can be addressed. Recent research has also presented methods for verifying and authenticating transmitted video data (Whitecotton, 2017; Harran et al., 2018).

CHAPTER II

METHODOLOGY

Multiple comparison paradigms were used to test this study's hypotheses. These paradigms can be summarized as follows. Understanding this comparison and analysis is facilitated by a detailed examination of the GoPro Fusion. The GoPro Fusion has two lenses attached to the body of the camera. There is a front-facing lens and a back facing lens. Both lenses have an f stop of 2.0. It is essentially two cameras in one body. The GoPro records to two separate micro SD cards, which work in tandem. While recording on the Fusion, the operator can either record using a standard electrical outlet or the camera's internal battery. The outlet on the camera is a USB-C style jack. The portable battery life of the GoPro is around 1.5 hours maximum. The system can be navigated using the button the front of the unit or by connecting to a cell phone via WiFi and using the GoPro application. Data can be written through the application, or to a mobile device, or the internal micro SD cards. Additional information can be stored to GoPro's cloud. The maximum resolution that can be recorded on the GoPro is 5.2K at 30 FPS (frames per second), NTSC or 25 FPS, PAL. Or 3k at 60 FPS. Frames per second are the number of frames of video that are captured each second when recording. The term 5.2k refers to the horizontal lines and the vertical number of pixels. At 5.2K, there are 4992 lines with a width of 2496 pixels. At 3k, there are 3000 horizontal lines and a width of 1504 pixels. An illustration of the different resolutions is shown below.

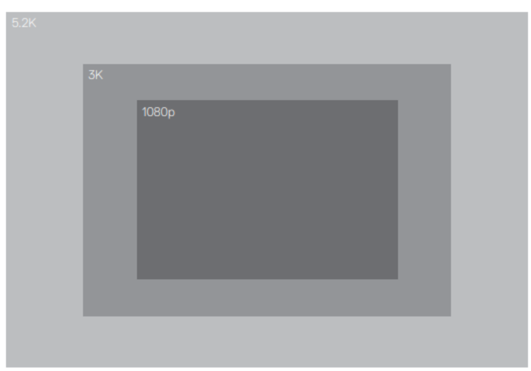

Figure 1 Illustration of GoPro Fusion Different Resolutions.

The aspect ratio of the recordings is made at 16:9. Aspect ratio is the ratio of the image's width to height. In this case, the image is 16 inches wide and 9 inches high. The purpose of a Go Pro 360 camera is to capture not only a front view but a complete image of the entire surround of the camera. The field of view (FOV) refers to how much of the subject is captured through the lens. The measurement is in degrees so that with the Go Pro camera, 360 degrees of the field of view. Therefore, the camera will capture the entire surrounding. The GoPro also has six (6) axes of stabilization. This increases camera stability in order to maintain smooth and steady shots. Protune is another feature on the GoPro Fusion as well as most of the products sold by the manufacturer. This feature allows the operator to be able to adjust both the International Standards Organization (ISO) and the Exposure Value (EV) level. ISO is used to adjust the overall brightness of the image. With a lower ISO setting, the image will be darker, but there will be less noise. With a higher ISO setting, the image will be brighter but will contain more noise. For the purpose of the tests used in this study, various ISO settings were used depending on the lighting situation. The settings available were 400, 1600 and 6400. EV, exposure value, ranges from -2.0 to +2.0. The default setting and what was recorded which was the EV set to (0). The higher the EV setting, the higher the brightness of the image. Protune is the ability to adjust the camera from auto settings to have more control by using variable ISO and EV settings. The GoPro Fusion, like many other digital cameras, has the capacity to adjust the date and time of the image acquisition. This information is stored within the metadata. When the device is connected either to the GoPro application or to the proprietary software, Fusion Studio, the date and time will auto adjust to whatever the actual device setting. This adjustment is relevant if the device is recovered for time offset purposes. Location of the device using GPS information is recorded as well. This information is only available when the fusion is connected to the GoPro application. This information is then stored within the metadata of the file. The GoPro features four built in microphones in order to capture audio all around the camera. The figure below depicts the various feature of the Go Pro 360 camera.

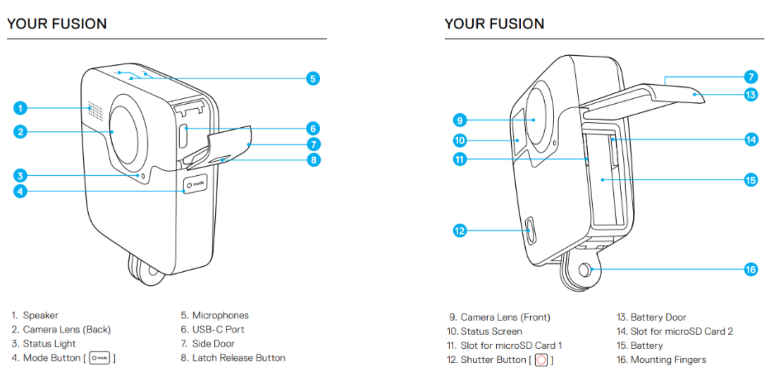

Figure 2 GoPro Fusion Diagram.

Another camera used in the tests in this study was the 360 Fly. This camera's original design purpose was for aviation and military use. The camera's navigation is controlled by a single button that can be used to pair to another device for total operating control. Once paired to another device, even more control over settings of the Fly can be maintained. Adjustments can be made for variables such as saturation, contrast, f speed and brightness. These are not necessarily detailed pro controls. They all feature a single slider, and they do not give numerical values of any specific degree of change is being made. Adjustment are not finite either. For the purposes of all test recordings performed in this study therefore, all settings were left at a neutral point. The Fly, like the GoPro, can record in many different resolutions. The maximum resolution that can recorded is at 2880 x 2880 with 30 frames per second. The aspect ratio is not 16:9 unless the camera is set to POV mode. Once that setting is made, further adjustments cannot occur including any changes to frame rates either. This camera features a single lens instead of having two lenses. The lens on the Fly is a single fisheye. A fisheye lens is one that shoots extremely wide images. The single lens can go to f 2.5. The field of view is again slightly different. Vertically, it has 240 degrees, and horizontally it has 360 degrees. Instead of recording two a SD card, the 360 Fly records internally with a total space capacity of 64gb. The battery life is slightly longer than the Go Pro, with the average time being two hours of battery life. The Fly 360 charges via a docking system that uses USB 2.0 technology. Like the Go Pro fusion, the Fly 360 stores GPS data within the metadata. This feature can be turned on or off within the settings on the Fly360 application. The features if the Fly are shown above.

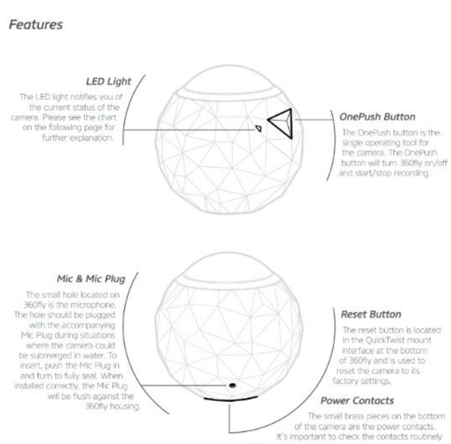

Figure 3 Diagram of 360Fly.

Various definitions are available for image recording. For the purpose of this study, recordings were made at the highest possible resolution to capture and store the most maximum amount of data possible. This procedure would allow the capture and analysis of the maximum change that occurs. All test recordings were at 5.2k on the GoPro at 30 frames per second. The Fly 360 recordings were at 2880 x 2880 at 30 frames per second. While it is possible to record with the Fly at 60 frames per second, the resolution would drop to 1728 x 1728.

Six recordings were collected and several types of data analysis were performed in order to compare any changes in the data acquisition and transfer. Files were then rendered out of the GoPro Fusion freeware, causing recompression in the files. The same process was done using the Fly360 test recordings. The recompressed files from the GoPro Fusion software were then recompressed through YouTube and analyzed.

The **Go Pro Fusion** software was used to create the 360 videos in multiple resolutions. Recording number one was used to create rendered file, VIDEO_0002.mov.

YouTube-dl was used to download the laundered videos from YouTube. Recording number one from the GoPro Fusion software, VIDEO_0002.mov, was used for the uploaded video to YouTube. The two YouTube files were created from this test as well, VIDEO_0002_yt-QQco8L093WY.mkv and VIDEO_0002_yt-QQco8L093WY.mp4

Matlab was used to analyze the PRNU, MDCT and ENF of the recordings. PRNU, (Photo Response Non-Uniformity) allows for identification of the unique characteristics of the camera's noise. Information using PRNU can be extracted and analyzed against the test database to see if the camera has support, limited support or no support to the images in the other camera in the database. MDCT was also analyzed. MDCT (Modified Discrete Cosine Transform) is designed to be performed on consecutive blocks of large data sets. It is not applied to an audio signal directly so that interference with the original data is minimized. The GoPro Fusion records audio in an AAC format. AAC is a ISO standard format that contains MDCT.

$$X_k = \sum_{n=0}^{2N-1} x_n \cos\left[\frac{\pi}{N}\left(n + \frac{1}{2} + \frac{N}{2}\right)\left(k + \frac{1}{2}\right)\right]$$

Figure 4 MDCT Equation.

LTAS (Long Term Average Spectrum) was performed on the audio data in order to record and demonstrate the mean, max, and min or the power. This helps us to define the overall recordings in the audio channel. ENF (electrical network frequency) was also evaluated in the audio recordings occurring in this study. ENF measures where noise from the main power supply is recorded into the actual recording. LCF, (low cut filter) was also measured. This variable provided information to determine if at a certain point, the audio recording has a low-cut filter that removes data from the low-frequency range. Recordings number one, GPBK0037.mp4, was used to analyze the PRNU. A Print Screen HQ was taken for analysis against the PRNU database. A Print Screen HQ was used as that is the best possible way currently, to extract a single frame from a recording using the native player. This recording had the best exposure settings for a neutral test. Recording number three, GPBK0121.mp4, was used for the MDCT, LCF and LTAS analysis. This recording was longer in length with more background noise for more information for analysis. This simulates a more realistic environment. Recordings four, GPBK0068.mp4 , five, GPBK0129.mp4, and six, GPBK0130.mp4, were used for ENF analysis. Recording four was made in an outdoor location, five was made in the same location as one and two but for a greater duration, under fluorescent lights and run off battery power. Six was made with the same conditions as five but plugged into the wall for power instead of running off battery power.

010 Editor was used to perform a hex analysis of the original recordings, recompressed recordings through YouTube and recompressed recordings through the creation of the 360 videos with the GoPro Fusion software. Hex analysis (hexadecimal) allows examination of the bytes of the file. From there, an analysis of the raw information can be made without it being encoded. Analysis of both the header and footer of this information can be completed to observe if any changes have been made from recompression, or any other changes have occurred including for example if the file has decreased or increased in size, and what is missing or has been added. Test recording one was used for this analysis as well as the first render from GoPro Studio and the two downloaded files from YouTube.

MediaInfo was used to assess the metadata and changes that occurred between the recompression of the videos in each stream. Metadata analysis was also used for this study to obtain a comparison between information is stored within the files. Test recording one, GPBK0037.mp4, the first render from the GoPro Studio, VIDEO_0002.mov, was used, the two downloaded files from YouTube were used VIDEO_0002_yt-

QQco8L093WY.mkv and VIDEO_0002_yt-QQco8L093WY.mp4, test recording number one from the Fly360, FLY08401.mp4 was used and the same recording but rendered out through the Fly360 director FLY08401(CONVERTED).mp4 was used in this test.

Exif tool was used to verify the results from the MediaInfo information. All recordings were used in this test.

FFmpeg was used to extract the audio stream from the video. All test recordings, one through six, had the audio stream extracted for analysis.

AtomicParsley was used to demonstrate the loss in atoms upon recompression of the video. Recording one, GPBK0037.mp4 and the recording rendered from the GoPro Fusion software, VIDEO_0002.mov were used.

The **Go Pro VR player** was used to playback the original recordings without having to render them and effectively alter the video as well as to create a print screen of the original file. The Print Screen HQ function was also utilized to extract the image for all of the PRNU tests.

The **GoPro app** was used to start and stop all recordings made.

The **360Fly app** was used to start and stop recordings and to adjust camera settings to the highest possible resolution.

Fly360 Director was used for the creation of the 360 videos from the additional 360 camera.

VLC was used in an attempt to play back the 360 video files without the GoPro native player. All test recordings were attempted to playback in VLC.

Paint Shop Pro was utilized to resize the images for the PRNU analysis. This was due to the unique size of the frame exported from the GoPro VR player.

In addition to comparing the two cameras, an examination was completed of the files after being uploaded and downloaded to YouTube. A popular way of sharing videos is by uploading them to the YouTube site. It is important to see the change that occurs between the original video and the recompression through YouTube. When recording to the GoPro Fusion, two files are created upon clicking record which captures a separate file per each lens. When these files are played back, they are warped and not playable as 360 videos yet. These videos must be imported into the GoPro Fusion software to create the 360 FOV videos. Two pieces of software are provided with the GoPro Fusion to aid with this data transfer. Upon rendering from the GoPro Fusion Studio, several options are available including Video codecs, H.264, CineForm '422 High' and Pro Res 422. For the purpose of this study, CineForm was used because it is likely to produce the least amount of recompression. Video resolutions was a second option. From 5.2k (4992 x 2496), 4k (3840 x1920), 3k (2880x1440), 2K (2048 x 1024_ are all available options. 5.2K was used in this study because it contains maximum data for the present study. Spatial Audio is the third option. Stereo was used for this study but 360 audio (Ambix) is another available option. Finally, DWarp (Parallax Compensation) is the final option. This setting was left on for this study because DWarp removes parallax lines in the raw stitched footage. Parallax is a displacement or difference in the apparent position of an object when viewed along two different lines of sight and is measured by the angle or semi-angle of inclination between those two lines.

Finally, the files were taken and uploaded to YouTube. This was to measure the recompression of the 360 files compared to the original data set to see what changes will occur upon download of the files.

For the data analysis, best practices for measuring authenticity or recompression in transferred data were utilized for transfer from GoPro Fusion's warped original files to a 360 playable format uploaded and downloaded from YouTube. These best practices have been written as guidelines by the Scientific Working Group on Digital Evidence (SWGDE). Image authentication is necessary to determine whether image data are accurate and valid representations of subjects and events. Importantly, these guidelines do not define specific analytic techniques or tools but a process to detect staging or manipulation of images in the manner of acquisition or transfer of images from one recording device to another. This process requires that the original image should be preserved, and any transferred image should maintain the integrity of the initially acquired data image. In this study, the transfer of data from the 360 GoPro to another device for data preservation is tested. An illustration of this image transfer and integrity are described in the article from SWGDE on, "Best practices for digital video evidence"

The discussion of this analysis includes the following topics:

1. Implications for authenticity and reliability when making data transfers of 360 video;
2. Directions for future research;
3. Best practices for collecting video data from the recording device;

The Scientific Working Group on Digital Evidence has also published guidelines on "Minimum requirements for testing tools used in digital and multimedia forensics." (SWGDE, 2018). These guidelines differentiate the critical forensic tools for preservation, acquisition, hashing, and wiping digital data. Multimedia tools for imagery enhancement and analog video capture are also addressed. The purpose of digital testing evidence is to assess the confidence level which can be assigned to a tool or procedure to perform correctly and reduce the risk of errors. In this study, the acquisition and transfer of video images using the GoPro Fusion 360 as well as the Fly360 was tested regarding the accuracy and validity of data moved from an original recording device to a second device. This process of transfer of video images is described in an applied legal article on the collection and production of technically sound and defensible digital data in a litigation process by Bowers (2018). He described several PDF pitfalls. Producing native files which hold all the metadata might be opened, corrupted, or inadvertently altered. Another problem can occur when multiple documents are produced in a single PDF without the original metadata being shown in a corresponding load file. The receiving party might then have to separate documents which could open the door to challenges from opposing counsel or even court sanctions. Bowers strongly urged the use of document specialists in the processing and management of native files. The specialist can identify common issues which are inaccurately collected and produced data. Bowers also noted that the common legal practice of Bates Numbering could produce even obvious errors in identifying where one document ends and the next one begins. He summarized the top four self-collection issues (Bowers, p.5):

1. A single PDF was created, which contained multiple documents without any delineation between those documents.
2. Metadata had been altered by employees simply forwarding requested emails.
3. Emails had been printed and then scanned into PDF which removed native metadata.
4. The inability to easily identify the melody of relationships of files.

He concluded, "Every attorney should approach each collection with the goal of making it forensically sound." (Bowers, p.7) He also noted, "Under the newly amended FRE 902, metadata will not be self-authenticating unless a qualified person has inspected the data, recorded the process used, and certified that an exact copy of the data was created." (Bowers, p. 6). This study was designed to test the hypothesis that there will be a significant change in the video data resulting in a loss of data accuracy due to recompression.

As a starting point to eliminate misleading data, SD cards were formatted on recording devices before use. To avoid camera motion, all recordings were made using a cell phone to start and stop recording. Version 01.70.00 of GoPro Fusion was used.

CHAPTER III

RESULTS

The metadata and file structure of the non-combined files were analyzed. 360 videos were captured to the GoPro fusion via two micro sd cards, one for each side of the camera, which were labeled 1 – 100GBACK (BACK) and 2 – 100GFRT (FRONT). One test recording was created for this research. One recording resulted in two files: GPBK0002 and GPFR0002. The tables below are a comparison of the metadata of the data collected through test recordings. Table 1 is of the metadata. You can see the format as well as file size changes between recompression. Table 2 is of the video content. Variances occur in multiple items in this table. From the aspect ratio to the bit rate. Table 3 is of the audio content and table. Again, multiple changes occur here. From the sample rate to even the duration. Four, five and six is additional metadata. In the original GoPro recording this information is stored but in all other form of recompression, including the Fly 360's recordings, this information is not stored.

Table 1

Metadata

Information	Original Recording (Recording 1, GPBK0037.mp4)	Go Pro Studio (Video_0002.mov)	YouTube Up Down MKV (VIDEO_0002_yt-QQco8L093WY.mkv)	YouTube UpDown MP4 (VIDEO_0002_yt-QQco8L093WY.mp4)	Fly 360 Original Recording (Fly360 Recording 1, FLY08401.mp4)	Fly 360 Rendered from the 360 Director software (Fly360 Recording 1 Render, FLY08401(CONVERTED.mp4)
Format	MPEG-4	MPEG-4	Matroska	MPEG-4	MPEG-4	MPEG-4
Format Version	n/a	n/a	Version 4 / Version 2			
Format Profile	N/A	Quicktime	n/a	Base Media	Base Media / Version 2	Base Media
Codec ID	mp41 (mp41)	qt 2005.03 (qt)	n/a	isom (isom/iso2/avc1/mp41)	mp42 (mp42/isom)	isom (isom/iso2/avc1/mp41)
File size	228 MiB	2.26 GiB	15.5 Mb/S	52.2 Mib	54.4 Mib	24.4 MiB
Duration	42 s 309 ms	42s 42ms	42 s 98ms	42 s 98ms	9 s 941ms	9 s 963 ms
Overall bit rate mode	Variable	Variable				Variable

Table 1 Cont

Metadata

Overall bit rate	45.2 Mb/s	461 Mb/s	15.5 Mb/s	10.4 Mb/s	45.1 Mb/s	20.6 Mb/s
Writing application	n/a	n/a	Lavf57.83.100	Lavf57.83.100		Lavf57.25.100
Writing Library	n/a	n/a	Lavf57.83.100	n/a		
Error Detection Type	n/a	n/a	Per Level 1	n/a		
xyz					+00.0000+000.0000/	

Table 2

Video

Information	Original Recording (Recording 1, GPBK0037.mp4)	Go Pro Studio (Video_0002.mov)	YouTube Up Down MKV (VIDEO_0002_yt-QQco8L093WY.mkv)	YouTube UpDown MP4 (VIDEO_0002_yt-QQco8L093WY.mp4)	Fly 360 Original Recording (Fly360 Recording 1, FLY08401.mp4)	Fly 360 Rendered from the 360 Director software (Fly360 Recording 1 Render, FLY08401(CONVERTED.mp4)
ID	1	1	1	1	1	1
Format	AVC	CineForm	VP9	AVC	AVC	AVC
MultiView_Count			2			
Format/Info	Advanced Video Codec			Advanced Video Codec	Advanced Video Codec	Advanced Video Codec
Format Profile	High@L5.1			High@L5.1	Baseline@L5.1	Baseline@L5.1
Format Settings	CABAC/1 Ref Frames			2 Ref Frames	1 Ref Frames	1 Ref Frames
Format settings, CABAC	Yes			No	No	No
Format settings, RefFrameS	1 Frame			2 Frames	1 Frame	1 Frame
Format settings, GOP	M=1, N=15				M=1, N=30	

Table 2 Cont

Video

Codec ID	Avc 1	CFHD	V_VP9	Avc 1	Avc 1	Avc 1
Codec ID/Info	Advanced Video Coding	CineForm High-Definition (HD) wavelet codec		Advanced Video Coding	Advanced Video Coding	Advanced Video Coding
Duration	42 s 309 ms	42 s 9ms	42s 9ms	42s 9ms	8 s 876 ms	9s 527ms
Source Duration					9 s 491 ms	
Bit Rate Mode	Variable	Variable				
Bit Rate	45.0 Mb/s	460 Mb/s		10.3 Mb/s	46.4 Mb/s	21.3 Mb/s
Width	2704 pixxels	5120 pixels	3840 pixxels	5120 piels	2880 pixels	3840 pixels
Height	2624 pixxels	2560 pixels	2160 pixels	2560 pixels	2880 pixels	1920 pixels
Display Aspect Ratio	1.030	2.000	16:9	2.000	1.000	2.000
Frame Rate Mode	Constant	Constant	Constant	Constant	Variable	Constant
Frame Rate	29.970 (30000/1001) FPS	29.970 (29970/1000) FPS	29.970 (30000/1001) FPS	29.970 (30000/1001) FPS	28.027 FPS	28.027 FPS
Minimum Frame Rate					1.542 FPS	
Maximum Frame Rate					37.943 FPS	
Color Space	YUV		YUV	YUV	YUV	YUV
Chroma subsampling	4:2:0			4:2:0	4:2:0	4:2:0
Bit Depth	8 Bits			8 Bits	8 Bits	8 Bits
Scan Type	Progressive	Progressive		Progressive	Progressive	Progessive
Bits/(Pixel*Frame)	0.212	1.171		0.026	0.200	0.103
Stream Size	227 MiB (100%)	2.25 Gib (100%)		52.5 MiB (99%)	49.0 MiB (98%)	24.1 MiB (99%)
Source Stream Size					52.4 Mib (98%)	
Title	GoPro AVC				Video Handle	
Language	English	English	English		English	
Default	n/a	n/a	Yes			
Forced	n/a	n/a	No			
Encoded Date	UTC 2018-08-23 11:37:56	UTC 2018-10-08 18:56:14			UTC 2018-10-24 21:56:54	
Tagged Date	UTC 2018-08-23 11:37:56	UTC 2018-10-08 18:56:14			UTC 2018-10-24 21:56:54	
Color Range	Full	n/a	Limited	Limited		

Table 2 Cont

Video

Color primaries	BT.709	BT.709	BT.709	BT.709		
Transfer characteristics	BT.709	N/a	Bt.709	BT.709		
Matrix coefficients	BT.709	BT.709	Bt.709	BT.709		
Mdhd_Duration					8876	
Writing library						x264 core 148 r2597 e86f3a1

*Only found on Fly rendered : Encoding settings : cabac=0 / ref=1 / deblock=0:0:0 / analyse=0:0 / me=dia / subme=0 / psy=1 / psy_rd=1.00:0.00 / mixed_ref=0 / me_range=16 / chroma_me=1 / trellis=0 / 8x8dct=0 / cqm=0 / deadzone=21,11 / fast_pskip=1 / chroma_qp_offset=0 / threads=12 / lookahead_threads=2 / sliced_threads=0 / nr=0 / decimate=1 / interlaced=0 / bluray_compat=0 / constrained_intra=0 / bframes=0 / weightp=0 / keyint=250 / keyint_min=25 / scenecut=0 / intra_refresh=0 / rc=crf / mbtree=0 / crf=23.0 / qcomp=0.60 / qpmin=0 / qpmax=69 / qpstep=4 / ip_ratio=1.40 / aq=0

Table 3

Audio

Information	Original Recording (Recording 1, GPBK0037.mp4)	Go Pro Studio (Video_0002.mov)	YouTube Up Down MKV (VIDEO_0002_yt-QQco8L093WY.mkv)	YouTube UpDown MP4 (VIDEO_0002_yt-QQco8L093WY.mp4)	Fly 360 Original Recording (Fly360 Recording 1, FLY08401.mp4)	Fly 360 Rendered from the 360 Director software (Fly360 Recording 1 Render, FLY08401(CONVERTED.mp4)
ID	2	2	2	2	2	2
Format	AAC	PCM	AAC	AAC	AAC	AAC
Format/Info	Advanced Audio Codec	N/a	Advanced Audio Codec	Advanced Audio Codec	Advanced Audio Codec	Advanced Audio Codec
Format Settings	n/a	Little/Signed	n/a			
Format Profile	LC	n/a	n/a	LC	LC	LC
Codec ID	mp4a-40-2	sowt	A_AAC-2	mp4a-40-2	mp4a-40-2	mp4a-40-2
Duration	42 s 304 ms	42s 42ms	42s 98ms	42 s 98 ms	9 s 941 ms	9 S 963 ms
Source Duration	n/a	42s 9ms	n/a			
Bit Rate Mode	Constant			Constant	Constant	Variable
Bit Rate	128 kb/s	1536 kb/s		126 kb/s	96.0 kb/s	126 kb/s
Channel(s)	2 Channels	-	-	-	-	-
Channel Positions	Front: L R	-	-	-	-	-
Sampling Rate	48.0 kHz	-	44.1 kHz	44.1 khz	48 kHz	48khz
Bit Depth		16 bits				
Frame Rate	46.875 FPS (1024 SPF)		43.066 FPS (1024 SPF)	43.066 FPS (1024 SPF)	46.875 FPS (1024 (SPF)	46.875 FPS (1024 SPF)
Compression Mode	Lossy		Lossy	Lossy	Lossy	Lossy
Stream Size	662 KiB(0%)	7.70 Mib (0%)		645 kib (1%)	117 kiB (0%)	153 Kib (1%)
Title	GoPro AAC	7.69 MiB (0%0				
Language			English	English		English
Default			Yes	Yes		Yes
Alternate group						1

Table 3 Cont

Audio

Forced			No			
Encoded Date	UTC 2018-08-23 11:37:56					
Tagged Date	UTC 2018-08-23 11:37:56					

Table 4

Other 1

Information	Original Recording (Recording 1, GPBK0037.mp4)	Go Pro Studio (Video_0002.mov)	YouTube Up Down MKV (VIDEO_0002_yt-QQco8L093WY.mkv)	YouTube UpDown MP4 (VIDEO_0002_yt-QQco8L093WY.mp4)	Fly 360 Original Recording (Fly360 Recording 1, FLY08401.mp4)	Fly 360 Rendered from the 360 Director software (Fly360 Recording 1 Render, FLY08401(CONVERTED.mp4)
ID	3	n/a				
Type	Time code	n/a				
Format	QuickTime TC	n/a				
Duration	42 s 309 ms	n/a				
Time code of first frame	12:01:17:21	n/a				
Time code, striped	Yes	n/a				
Title	GoPro TCD	n/a				
Language	English	n/a				
Encoded Date	UTC 2018-08-23 11:37:56	n/a				
Tagged Date	UTC 2018-08-23 11:37:56	n/a				
Bit Rate Mode	CBR	n/a				

Table 5

Other 2

Information	Original Recording (Recording 1, GPBK0037.mp4)	Go Pro Studio (Video_0002.mov)	YouTube Up Down MKV (VIDEO_0002_yt-QQco8L093WY.mkv)	YouTube UpDown MP4 (VIDEO_0002_yt-QQco8L093WY.mp4)	Fly 360 Original Recording (Fly360 Recording 1, FLY08401.mp4)	Fly 360 Rendered from the 360 Director software (Fly360 Recording 1 Render, FLY08401(CONVERTED.mp4)
Type	meta	-				
Duration	42 s 42ms	-				
Bit Rate Mode	CBR	-				

Table 6

Other 3

Information	Original Recording (Recording 1, GPBK0037.mp4)	Go Pro Studio (Video_0002.mov)	YouTube Up Down MKV (VIDEO_0002_yt-QQco8L093WY.mkv)	YouTube UpDown MP4 (VIDEO_0002_yt-QQco8L093WY.mp4)	Fly 360 Original Recording (Fly360 Recording 1, FLY08401.mp4)	Fly 360 Rendered from the 360 Director software (Fly360 Recording 1 Render, FLY08401(CONVERTED.mp4)
Type	meta	n/a				
mdhd_Duration	42309	n/a				
Bit rate mode	VBR	n/a				

Below, is the first hex analysis. The file was imported into 010 editor. You can see information such as the version number, name of the camera and the file type. This matches what we have found in the mediainfo data above.

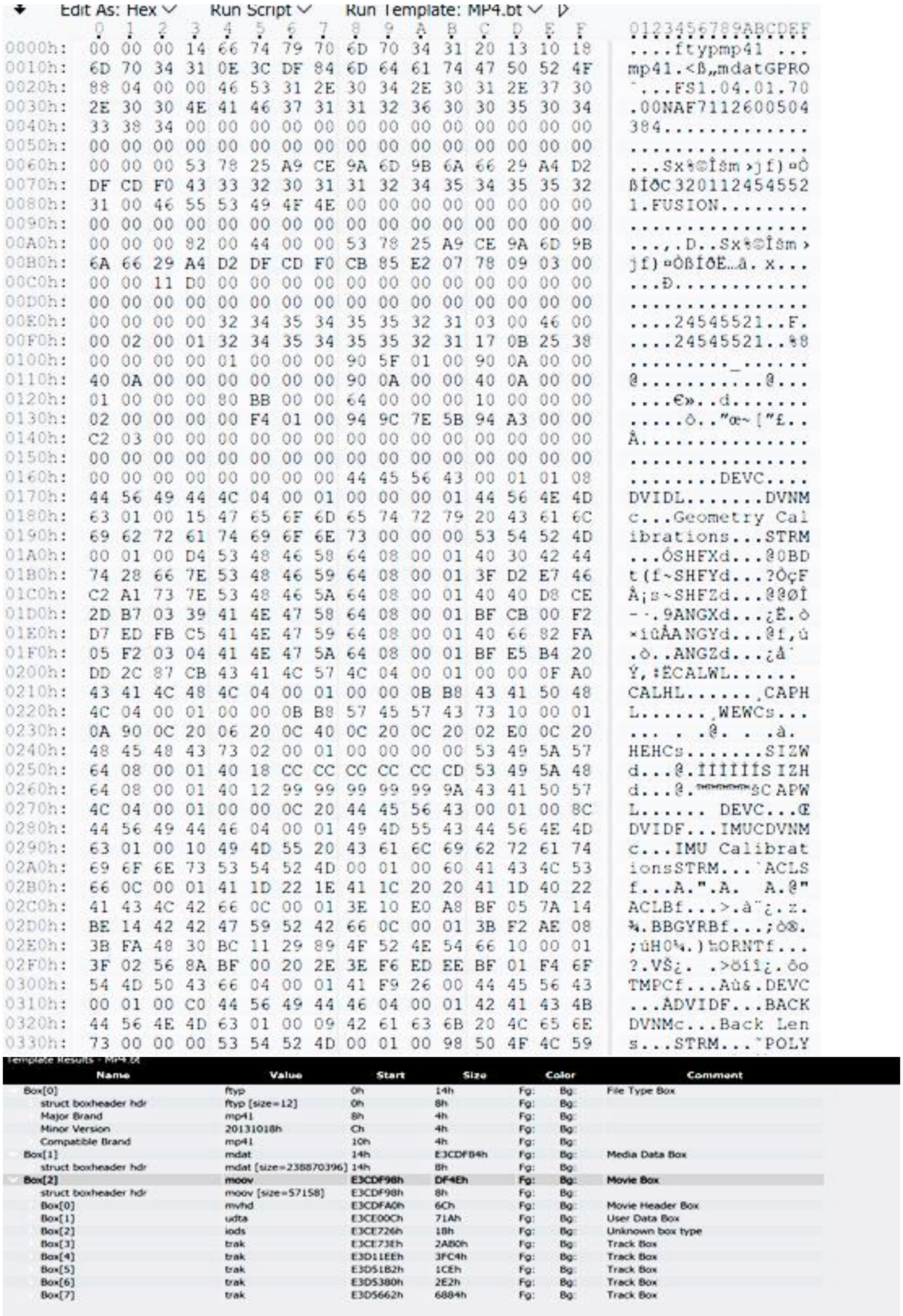

Figure 5 Hex Analysis: Original. Note. In hex analysis, front lens still notates back and front. Test is done 0002 and (Recording 1 GPBK0037.mp4)

During export, a selection of destinations is offered: editing, Facebook, YouTube, or Vimeo. Different resolutions may be selected as well: 5.2k, 4k, 3k, and 2k. Audio may also be exported in stereo or 360 audio, called "Ambix." When using GoPro studio to combine the front and back to make an actual stitched 360 video, the name is adjusted to VIDEO_0002 upon export. The file was rendered using export destination "Editing" in 360 Media Resolution 5.2k with the audio setting Stereo. This is the highest export resolution allowed out of the GoPro fusion software at this time. The hex analysis below is of the rendered 360 file from the GoPro Fusion through the fusion studio software. You can see the changes that occur between the original recording and recompressed recording.

Figure 6 Hex Analysis of the Files Rendered out of the GoPro Fusion Studio Software. File is VIDEO_002.mov. Much less information is now stored in the header.

Template Results - MP4.bt

Name	Value	Start	Size	Color	Comment
Box[0]	ftyp	0h	14h	Fg: Bg:	File Type Box
struct boxheader hdr	ftyp [size=12]	0h	8h	Fg: Bg:	
Major Brand	**qt**	**8h**	**4h**	**Fg: Bg:**	
Minor Version	20050300h	Ch	4h	Fg: Bg:	
Compatible Brand	qt	10h	4h	Fg: Bg:	
Box[1]	mdat	14h	9078C73Ch	Fg: Bg:	Media Data Box
struct boxheader hdr	mdat [size=24238344	14h	10h	Fg: Bg:	
Box[2]	moov	9078C750h	2AF0h	Fg: Bg:	Movie Box
struct boxheader hdr	moov [size=10984]	9078C750h	8h	Fg: Bg:	
Box[0]	mvhd	9078C758h	6Ch	Fg: Bg:	Movie Header Box
Box[1]	trak	9078C7C4h	1BEBh	Fg: Bg:	Track Box
Box[2]	trak	9078E3AFh	75Ah	Fg: Bg:	Track Box
Box[3]	trak	9078EB09h	343h	Fg: Bg:	Track Box
Box[4]	udta	9078EE4Ch	3F4h	Fg: Bg:	User Data Box

Figure 6 Cont. Hex Analysis of the Files Rendered out of the GoPro Fusion Studio Software

Below is an atom breakdown using AtomicParsley to demonstrate the loss of metadata between the captured raw video and the rendered 360 video.

Table 7

Atoms of the Original Recording

AtomicParsley comparison between the original files and stitched files
Atom ftyp @ 0 of size: 20, ends @ 20
Atom mdat @ 20 of size: 238870404, ends @ 238870424
Atom moov @ 238870424 of size: 57166, ends @ 238927590
Total size: 238927590 bytes; 114 atoms total. AtomicParsley v0.8
Media data: 238870404 bytes; 57186 bytes all other atoms (0.024% atom overhead).
Total free atoms: 162 bytes; 0.000% waste.

Table 8

Atoms of the 360 Recompressed Video

Atomic Parsley stitched file:
Atom ftyp @ 0 of size: 20, ends @ 20
Atom mdat @ 20 of size: 1, ends @ 21
Atom dat @ 21 of size: 365, ends @ 386
Total size: -1871121856 bytes; 15 atoms total. AtomicParsley v0.8 Media data: 0 bytes; 2423845440 bytes all other atoms (-129.540% atom overhead). Total free atoms: 0 bytes; 0.000% waste.

In Summary, the important observation is the reduction in the amount of atoms between the original recording and recompressed the video. Even though the file size increases, the amount of data stored within the metadata of the file is much less.

YouTube Up Down

After rendering video out, the video was uploaded to YouTube using YouTube-dl. After a wait of 2-3 hours to ensure that all formats were downloadable from YouTube, the file was downloaded using the -F function in YouTube-dl:

Mp4 = merged 138,140 (YouTube format selection on YouTube-dl)

MKV= YouTube-dl automated choice

The Mp4 file is now at a frame rate of 29.97 and has a resolution of 5120x2560

The MKV file is now at a frame rate of 29.97 and has a resolution of 3840x2160

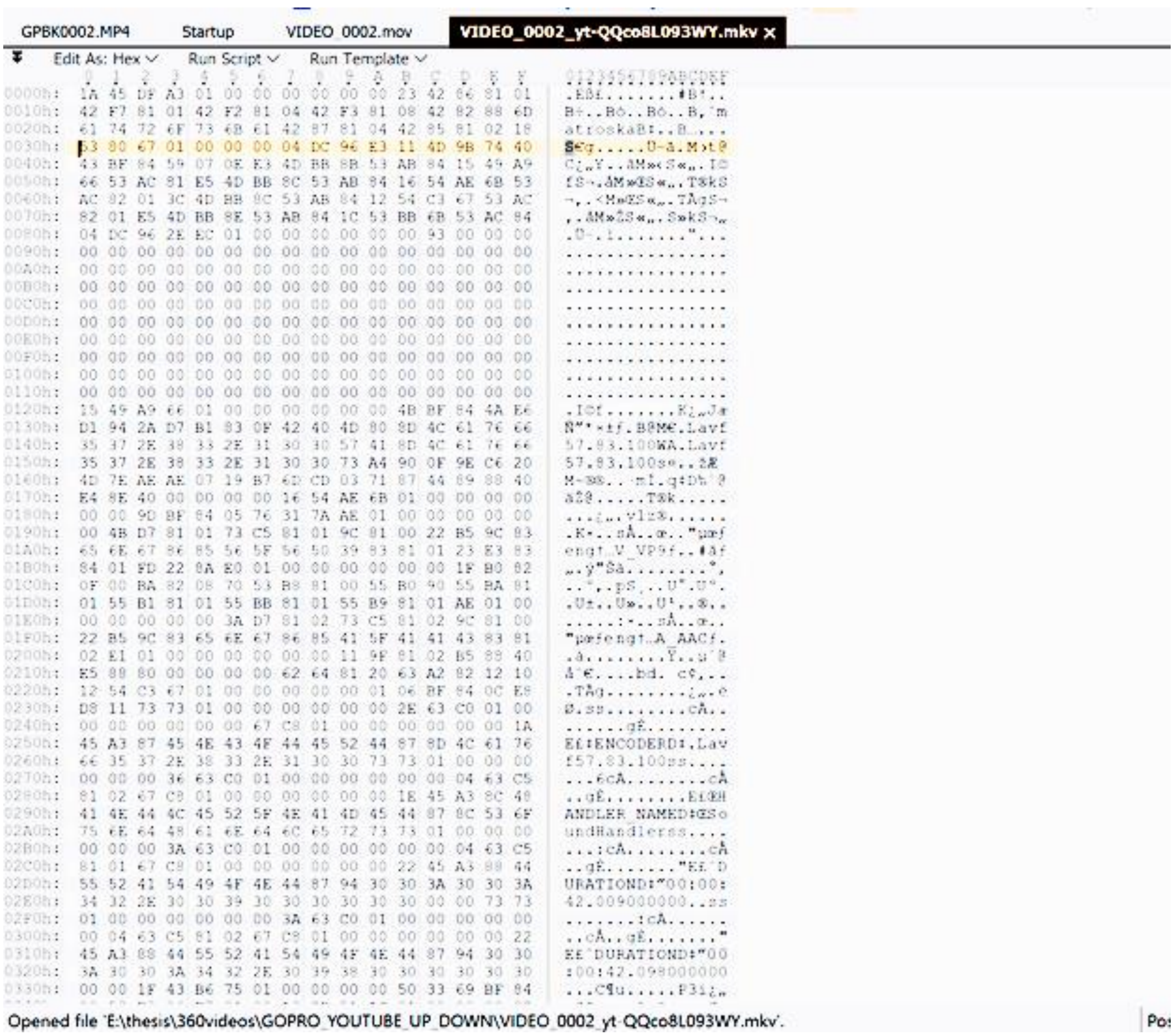

Figure 7 Hex Analysis of the Files Downloaded from YouTube in the MKV File Type. File is VIDEO_0002_yt-QQco8L093WY.mkv. Information has now been changed again in the header.

Name	Value	Start	Size	Color		Comment
Box[0]	ftyp	0h	20h	Fg:	Bg:	File Type Box
struct boxheader hdr	ftyp [size=24]	0h	8h	Fg:	Bg:	
Major Brand	isom	8h	4h	Fg:	Bg:	
Minor Version	200h	Ch	4h	Fg:	Bg:	
Compatible Brand[0]	isom	10h	4h	Fg:	Bg:	
Compatible Brand[1]	iso2	14h	4h	Fg:	Bg:	
Compatible Brand[2]	avc1	18h	4h	Fg:	Bg:	
Compatible Brand[3]	mp41	1Ch	4h	Fg:	Bg:	
Box[1]	free	20h	8h	Fg:	Bg:	Free Space Box
struct boxheader hdr	free [size=0]	20h	8h	Fg:	Bg:	
Box[2]	mdat	28h	3428C0Eh	Fg:	Bg:	Media Data Box
struct boxheader hdr	mdat [size=54692870]	28h	8h	Fg:	Bg:	
Box[3]	**moov**	**3428C36h**	**AB4Ah**	**Fg:**	**Bg:**	**Movie Box**
struct boxheader hdr	moov [size=43842]	3428C36h	8h	Fg:	Bg:	
Box[0]	mvhd	3428C3Eh	6Ch	Fg:	Bg:	Movie Header Box
Box[1]	trak	3428CAAh	44DEh	Fg:	Bg:	Track Box
Box[2]	trak	342D188h	6596h	Fg:	Bg:	Track Box
Box[3]	udta	343371Eh	62h	Fg:	Bg:	User Data Box

Figure 7 Cont. Hex Analysis of the Files Downloaded from YouTube in the MKV File Type

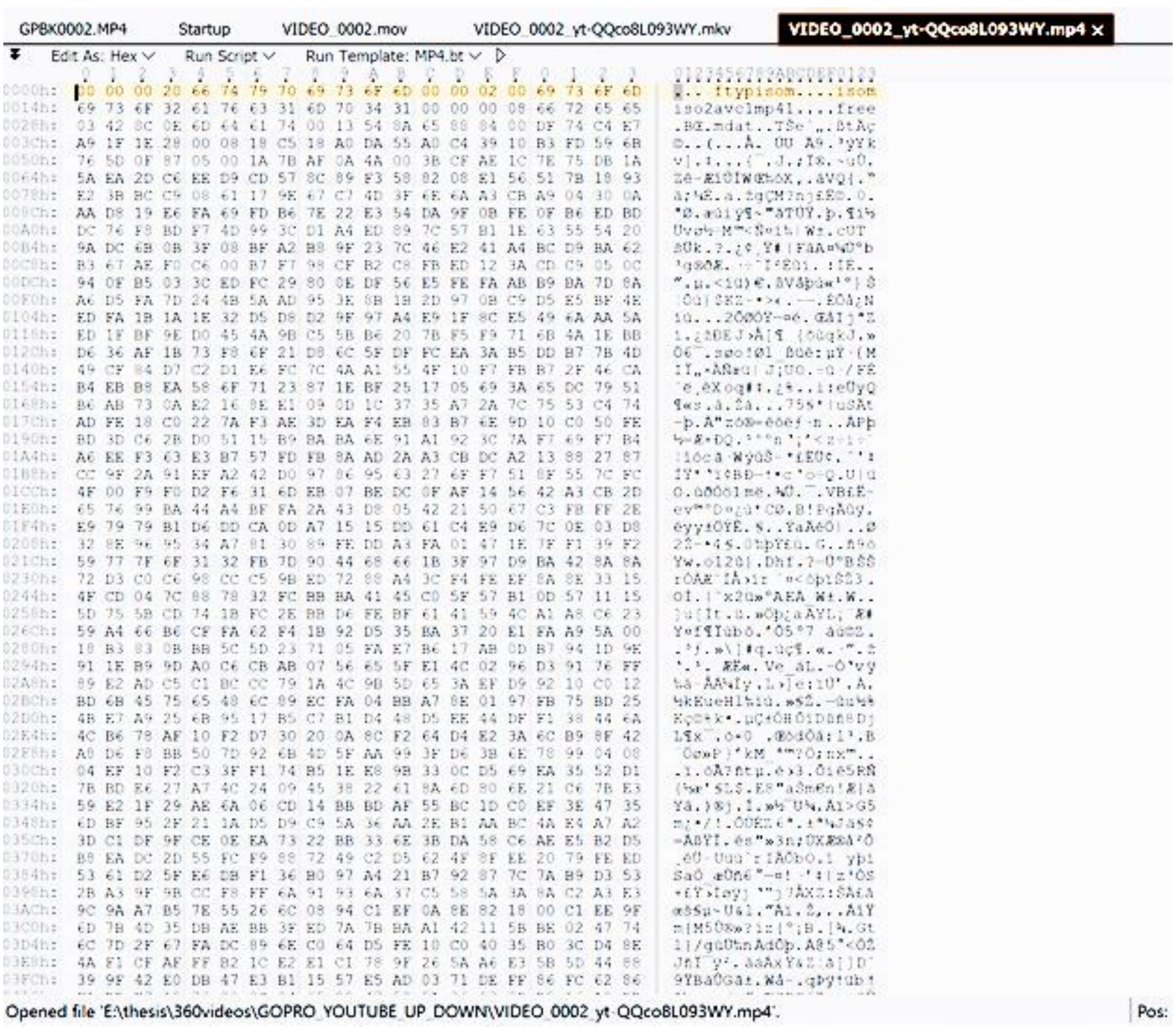

Figure 8 Hex Analysis of the Files Downloaded from YouTube in the MP4 File Type. File is VIDEO_0002_yt-QQco8L093WY.mp4. We now have additional information stored with in the header but the information is still differs from the original.

Template Results - BaseMedia.bt

Name	Value	Start	Size	Color	Comment
ftyp[0]		0h	20h	Fg: Bg:	
File type[4]	isom	8h	4h	Fg: Bg:	http://ftyps.com/
ubyte data[20]		Ch	14h	Fg: Bg:	
uuid[1]		20h	397h	Fg: Bg:	
ubyte data[919]		20h	397h	Fg: Bg:	
moov[2]		3B7h	2360h	Fg: Bg:	
mvhd[0]		3BFh	6Ch	Fg: Bg:	
trak[1]		42Bh	C77h	Fg: Bg:	
trak[2]		10A2h	1613h	Fg: Bg:	
udta[3]		26B5h	62h	Fg: Bg:	
free[3]		2717h	1D8E9h	Fg: Bg:	
ubyte data[121065]		2717h	1D8E9h	Fg: Bg:	
mdat[4]		20000h	1849385h	Fg: Bg:	

Figure 8 Cont. Hex Analysis of the Files Downloaded from YouTube in the MP4 File Type

Significate changes in the header have occurred with the recompression through YouTube. Even between the MKV file and the MP4 file the amount of data stored within the header varies due to the recompression of the files. New data has overwritten the original data.

PRNU Results

A "print screen HQ" was taken from the GoPro VR Player and a PRNU analysis was run against it. Print screen HQ was used due to the inability to export a frame and this was the best option provided with the current features of the GoPro VR Player. Two cameras were tested against the GoPro after resizing using Paint Shop Pro to match the abstract size of the print screen file (2020 x1371). Currently, this is the best practice for exporting a frame from an original recording without having to use the Fusion editing software. A comparison was made between a Sony Falcon and a Canon PowerShot. The red histogram is a comparison of the evidence PRNU against the suspect camera and database. The database contains videos from various other cameras PRNU. The blue histogram shows the suspect camera intra-variability while red histogram shows the suspect and data base inter-variability. Finally, the green histogram shows the position of evidence against the two, suspect and database. The results were as follows:

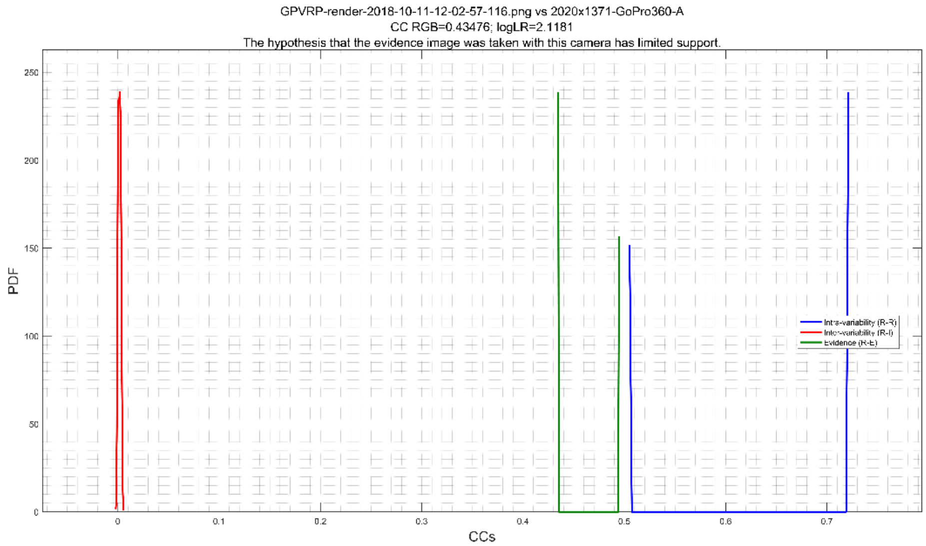

Figure 9 GoPro Rendered File Comparison to GoPro.

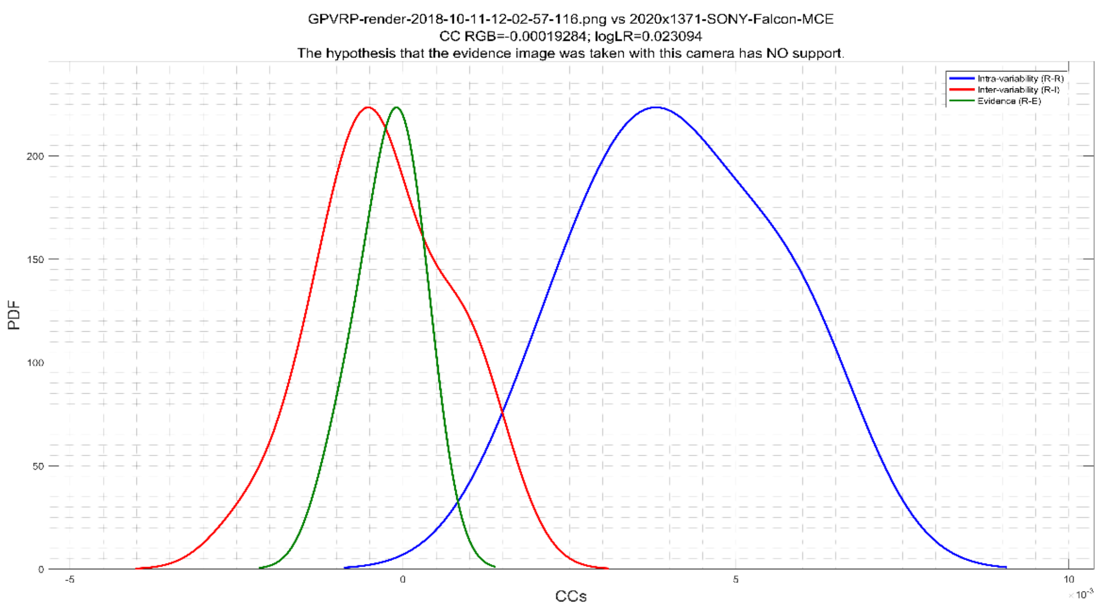

Figure 10 Go Pro Comparison to Sony Falcon.

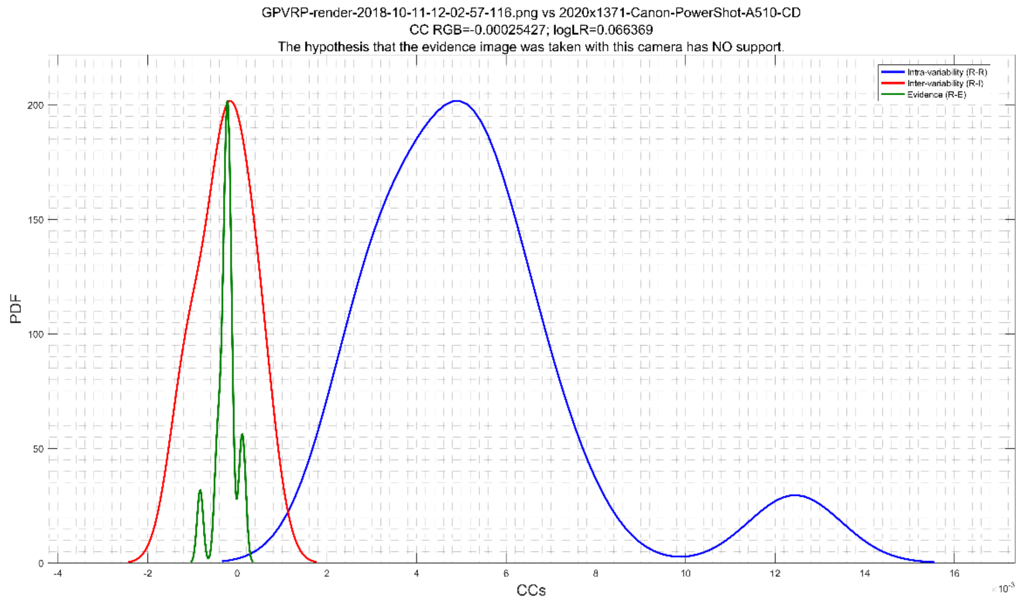

Figure 11 Go Pro Comparison to Canon PowerShot.

Figure 12 Image Used for First PRNU Tests. This was extracted using the “Print Screen HQ” function within the GoPro VR Player software.

Figure 13 A Screenshot from the 360 Point of View Taken from the GoPro Studio Software Before Rendering.

Figure 14 A Screenshot from the Fish Eye Point of View Taken from VLC Upon Playback.

Attempting to playback recording 1 in VLC results in a fish eye image. The image is warped and the color temperature is slightly different.

Figure 15 Image Captured from the 360Fly as the Fisheye Perspective.

Figure 16 Image Captured from the 360Fly as the 360 Perspective, Camera Not Moved.

Audio Results

Using ffmpeg, the audio was extracted from the test recordings, renderingGPBK0102.mp4, GPBK0103.mp4, VIDEO_0102.mov, VIDEO_0102.mov. The stereo file was split to two mono channels to be read by Matlab script:

```
FFmpeg -i stereo.wav -map_channel 0.0.0 left.wav -map_channel 0.0.1 right.wav
```

When the video was recorded in the classroom with a low-level recording, the microphone picked up ENF as seen at 52 Hz and 120hz in the spectral analysis. To verify this finding, a separate recording was made outside without around any lighting sources, and no ENF was found in the second spectral analysis.

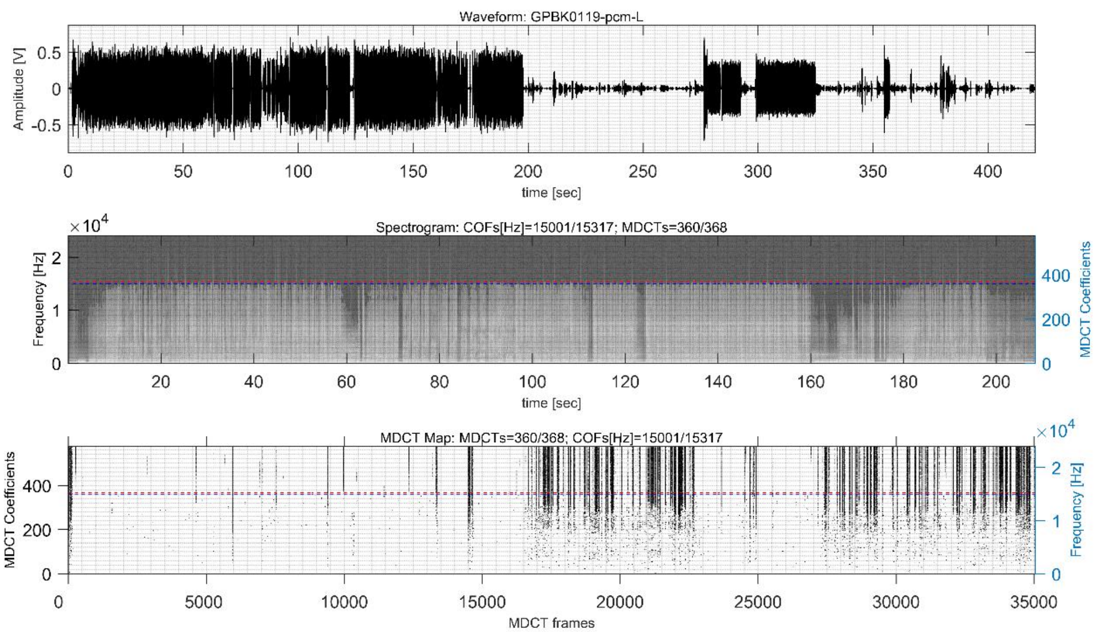

Figure 17 Waveform, Spectrogram and MDCT Map.

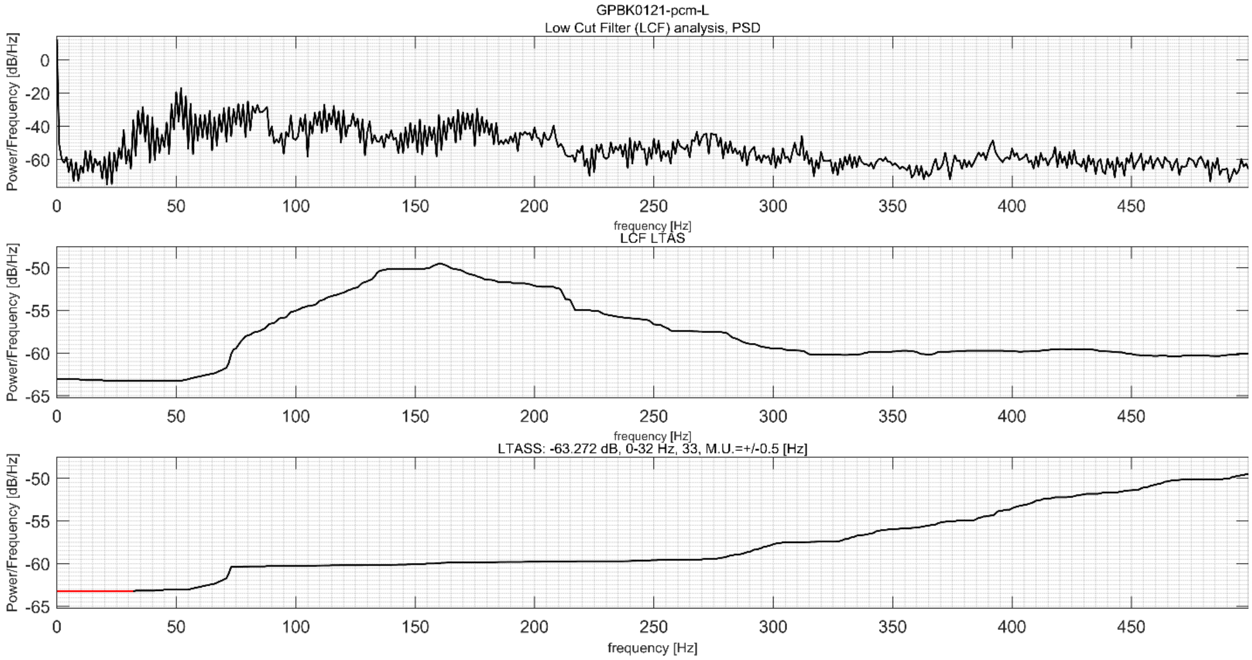

Figure 18 LCF Analysis.

As indicated in the graph above, there is a roll off just below 50 hz. This was found in multiple recordings and no settings to adjust this.

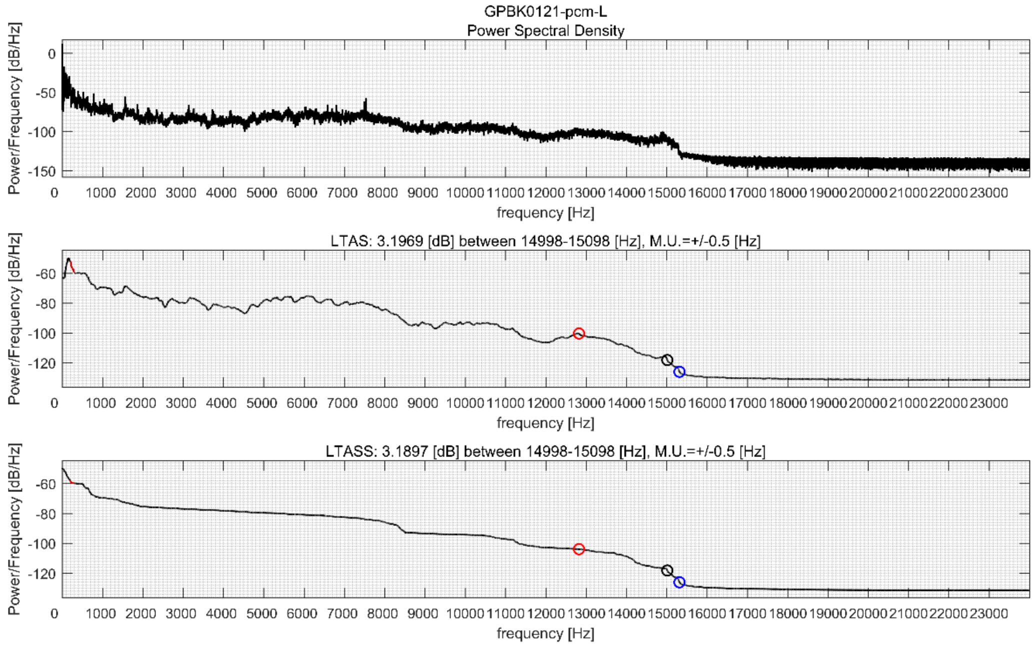

Figure 19 LTAS Analysis.

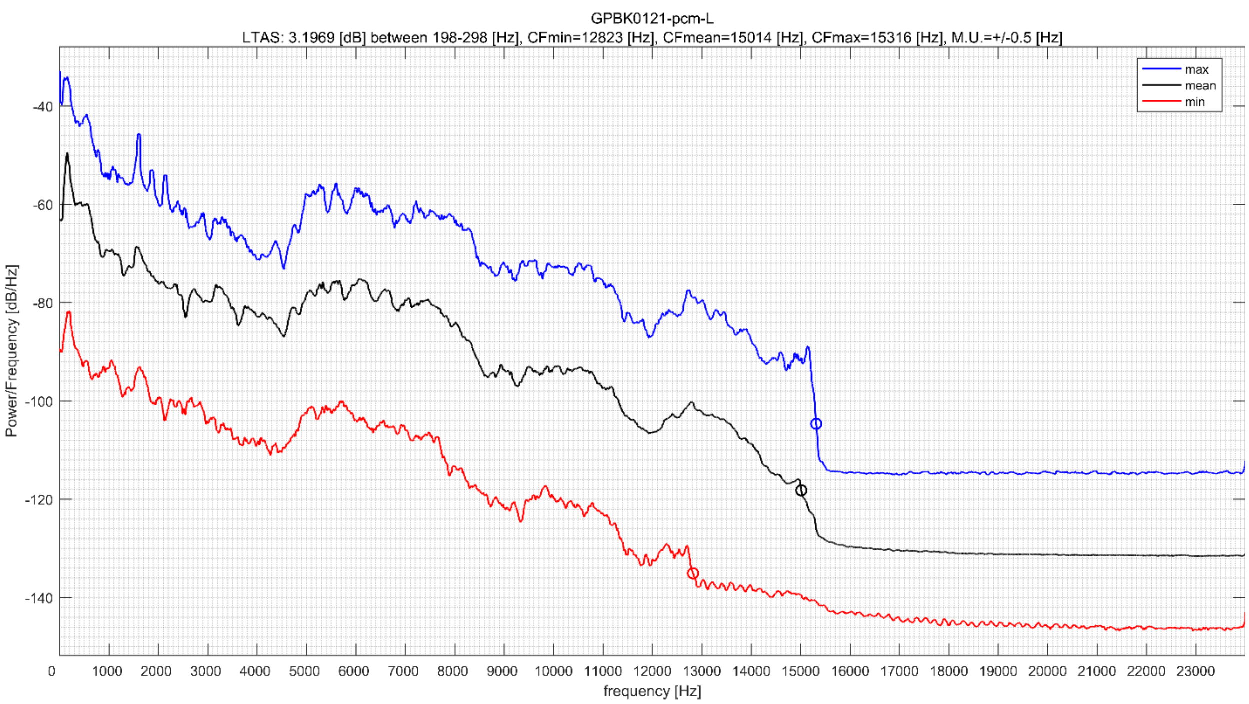

Figure 20 LTA Analysis Two.

CHAPTER IV

DISCUSSION

The fact that exporting a file via the GoPro VR player as an uncompressed image is not possible, which presents multiple issues because without opening the video in the player, the original image is warped and will not play back in a native player. A screenshot can be taken via the “print screen” or “print screen HQ.” The result is a PNG file from the print screen HQ. The only way to render a video that has been stitched together out of the native player is to use the freeware Fusion Studio. As noted, most of the metadata is lost when using this editing software. After rendering the 360 files, the file size increased while the meta data decreased. PRNU (Photo Response Non-Uniformity), which describes the gain between power on a pixel versus the signal output. It is well defined on the GoPro Fusion, and there is no support for the two selected files. This is one measure of detecting manipulation when metadata and hex analysis fall short.

It can be concluded from these results that the inability to play 360 videos at this time with native players while they are warped using conventional tools such as FFmpeg or even QuickTime presents multiple problems for the forensic community. Having a stitched file results in the file being laundered and losing a lot of metadata. It is evident by the size of the atoms that the amount of information removed to get a 360 video in a playable format is quite significant. Without additional information provided from GoPro, geometry calculations are difficult. Information can be found in the file headers, but no information is provided from GoPro. Also notable is that data on both the back and front lenses are listed, with the meta data containing differing serial numbers between the two lenses.

Conclusion

The tested hypothesis was substantiated. A reduction in data from the recompression of the original recordings was found. Future research should be conducted to evaluate newer versions of the GoPro Fusion as well as the GoPro Fusion studio software. Further testing should also be done on different videos resolutions, with other makes of 360 videos, and with other upload mediums, such as Facebook or Twitter. A recording should be collected while the camera is connected to the power source in the wall or, if it is still captured, then via the mic. Additional research on whether ENF information is stored within the video or just in the audio is also recommended.

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