BUTT-SPLICE DETECTION

ON AUDIO RECORDINGS

WITH LOSSY COMPRESSION

by

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B.S., University of Colorado, 2015

A thesis submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirements for the degree of

Master of Science

Recording Arts Program

2020

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Date: December 12, 2020

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Butt-Splice Detection on Audio Recordings with Lossy Compression

Thesis directed by Associate Professor Catalin Grigoras

ABSTRACT

A 'butt-splice' is a digital audio edit that results from deleting a portion of audio from a recording, or otherwise bringing together two non-contiguous portions of audio. This effect is not necessarily detectable by simply listening to the audio or combing through its waveform. As a result, spotting these edits is a potential means of identifying malicious forgery. A detection script can be used to mitigate human error in the pursuit of finding these alterations.

Lossy compression is a form of digital encoding that removes information from audio to reduce its size. This process sacrifices fidelity in pursuit of minimizing storage. As the bitrate decreases, the greater loss of data and the higher degradation relative to the original file. Additionally, certain compression types apply a low-pass filter that cuts off high frequencies.

As butt-splices tend to introduce a high-frequency transient due to the sudden jump in sample values they produce, detection of the removed area may be masked by the compression process itself. Whereas in an uncompressed version of the same file, which may be more easily detected. It is the aim of this document to discern whether a detection algorithm can find evidence of tampering in audio that has been edited with butt-splicing and then compressed.

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

Approved: Catalin Grigoras

ACKNOWLEDGEMENTS

I'd like to acknowledge some individuals and inanimate objects that were invaluable assets in the completion of this document, people and things that without whom this thesis would either toil in the catacombs of my mind, a perpetual prisoner to postponement, or be a much poorer addition to the scientific hivemind.

Firstly, a heaping helping of thanks to my thesis committee for your guidance during the construction of this pile of paper and throughout the program, Cole for his green chili recipe and early encouragement, Doug for mingling among the student scum as a covert professor, Jeff for his meticulous SGLs and less meticulous karaoke skills, and Catalin for the data assistance and his superhuman knowledge of all things media.

A further helping heaping to my fellow cohort members. Aside from bar hopping through Seattle, forming an impromptu cover band, and sharing the eternal struggle for knowledge and job security, you also were much faster than me at finishing your respective theses, thus providing many fine examples of how to best structure my own. Thank you for rewarding my procrastination with your superior work ethic.

Thanks to my parents, Dede and Barb, for their unflinching support, not just over the years of this Masters, but the 26 before and the couple I have remaining to me after. Thanks to Kristin for graph assistance, tireless encouragement, and general sweet loveliness. Thanks to Patrick for growing up with me and cultivating a mutual respect for intellectual pursuits that allowed me to even seek out such a degree. Thanks to Nathan for being a constant enabler of my strange ideas and having the considerable talent to bring them to fruition.

Lastly, I'd like to dedicate this thesis to coffee, that acidic elixir that kept me upright when I otherwise would surely be bumbling my way through a semiconscious existence.

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INTRODUCTION

Overview

When a section of audio is removed from a recording without the use of crossfade interpolation, the raw sample points directly before and after the selection merge, creating a stark amplitude discontinuity. This type of edit is referred to as a ‘butt-splice’. As the effect takes place at the minute sample level, a detection script must be used to mitigate human error in the pursuit of spotting these alterations.

Lossy compression is a form of digital encoding that removes repetitive information from audio to reduce its size, resulting in a loss of fidelity. As the bitrate decreases, the greater the loss of quality from the original recording.

The purpose of this study is to examine the effects that lossy compression has on the detection of butt-splice edits in a waveform. The primary goals of this analysis are to determine:

1. Does lossy compression mask the detection of butt-splice edits?
2. Do different lossy compressions have different effects on detection?
3. Do different bitrates have different effects on detection?
4. Do different splice values have different effects on detection?
5. What are the thresholds at which edits are no longer detectable?

The results of this research are intended to assist with the identification of an audio file as either unedited or edited with a process that produces butt-splices. By verifying characteristics of three common compression types (AAC, MP3, and WMA) and comparing them with their edited and unedited uncompressed originals (WAV), it is hoped that any possible limitations of this detection method can be identified and accounted for in future research.

Prior Research

Though minimal, prior research on the detection of butt-splice edits is available. Primarily, Alan J. Cooper's paper *Detecting Butt-Spliced Edits in Forensic Digital Audio Recordings* [2] with the London Metropolitan Police Digital & Electronics Forensic Service was presented at the Audio Engineering Society's 39th International Conference in June 2010.

In his paper, Cooper describes how editors often use butt-splices that leave their edit points exposed, rather than using a crossfade technique that might mask the forgery more effectively. Due to this oversight, an unnatural amplitude jump remains when such an edit is made. This situation can be exploited by locating the time domain sample where this discontinuity occurs by using a MATLAB script that detects the highest amplitude jump between two consecutive samples.

The script works by scanning the initial audio signal for a 1^{st} and 2^{nd} derivative between adjacent signal samples and high pass filtering it to model a discontinuity at higher frequencies where the discontinuity energy to acoustic signal level is improved. The model is then used as a template, computing the cross-correlation coefficient at each consecutive audio sample point, searching for potential edits in the audio data [2].

Cooper concludes by stating that his detection algorithm is superior to the previous method of traditional auditory and visual waveform analysis because it does not rely on error-prone human interpretation. Without an unbiased mechanism to discern potential splicing, the findings of this study would be far less valid.

Limitations

The scope of this study is limited to the three lossy compression types (MP3, WMA, AAC) and four bitrate values (32, 64, 128, 256) that were tested. Any codecs or bitrate settings beyond these may produce conclusions that vary from those drawn here. This document makes no attempt to decipher the mechanisms by which lossy algorithms process the original files they compress. It instead focuses on whether a peer-reviewed detection script can accurately identify the edited sample point when fidelity is reduced by the compression these codecs apply.

Terminology

Table 1: Terminology

Term	Definition
AAC	Advanced Audio Coding is a lossy compression format. Developed as a successor to MP3, AAC attempts to achieve greater fidelity while maintaining the same loss of redundant information.
Bitrate	The number of bits per second that can be transmitted along a digital network. The lower the number, the lower the audio fidelity.
Butt-Splice	An audio edit wherein a section is removed from an original recording without crossfade interpolation, resulting in the merging of the raw sample points directly before and after the selection.
Crossfade Interpolation	An audio process by which the sample points that merge when a selection is removed from a waveform are blended with a gradual lowering and rising of volumes between the two remaining clips.
Discontinuity	After a butt-splice, the amplitude of the samples on either side of the splice point will not be in equilibrium, making an abrupt jump.
Highest Jump	The point in a waveform between two consecutive samples (K and K+1) with the greatest change in amplitude.
High Pass Filter	An audio process that removes frequencies above a set value and attenuates the frequencies below that value.

Table 1: Continued

Term	Definition
Lossy Compression	A form of encoding that removes redundant data in an original file to reduce its value at the expense of fidelity.
Low Pass Filter	An audio process that removes frequencies below a set value and attenuates the frequencies above that value.
MP3	MPEG Audio Layer III is a lossy compression format originally developed as the audio layer of the MPEG video format.
PCM	Pulse code modulation is an uncompressed audio method that is used to convert an analog signal into a digital signal so that a modified analog signal can be transmitted through the digital communication network.
Quantization Levels (QL)	The measure of quantized amplitude samples.
Samples	A single discrete element forming part of a digital audio signal that represents where data occurs on the time domain.
Splice Value	The difference in amplitude between two samples that have been connected when a butt-splice is made.
Threshold	The point at which a characteristic of an edited file (bitrate, compression type, or splice value) starts to report false detections.
Uncompressed Audio	A form of encoding that has no loss of fidelity from digitization. All data is reconstructed exactly from the original.
WAV	Waveform Audio File Format is an audio file container format standard developed by Microsoft and IBM.
Waveform	A visual representation of audio data presented in editing software where the time at which a sample occurs is measured in the horizontal axis and amplitude quantization levels are measured in the vertical axis.
WMA	Windows Media Audio is a lossy compression format developed by Microsoft to compete with MP3.
Zero-Level Padding	An aspect of the lossy compression process that pads a compressed file with newly added silence at the beginning of the waveform. The number of zeros added depends on the codec and software used.

CHAPTER II

METHODOLOGY

Materials

To produce the findings of this study, a selection of materials were utilized to conduct experiments on controlled audio files. The original recordings were captured in uncompressed WAV format on a Samsung phone. These files were imported into Adobe Audition and altered with butt-splice edits. The edited files were then transcoded with lossy compression via FFmpeg. With the full dataset created, each file was run through the MATLAB detection script, the results of which were catalogued in Microsoft Excel.

Table 2: Materials

Material	Version	Description
Samsung Phone	Galaxy S10+	This cellphone's Voice Recorder application was used to capture audio.
Adobe Audition	CC 13.0.10	An audio editing software that allows users to import audio files into a workspace and process or alter its waveform in various ways.
FFmpeg	4.3.1	A command line tool for the purpose of digital audio processing and conversion.
MATLAB	R2020b	A multi-purpose mathematics software that allows users to write custom scripts to analyze digital content based on peer-reviewed techniques.
Microsoft Excel	2019 16.0.6742.2048	A spreadsheet creation software that allows users to organize data into tables and graphs with automatic formula calculation built in to mitigate human error.

Procedure

Capturing Audio

The original uncompressed audio recordings, which all lossy versions were derived from, consisted of 10 low-level room noise recordings of roughly 10 seconds in length. Room noise was used, opposed to a more complex waveform like recorded speech, because it would allow for a greater amplitude consistency to mitigate false positives that may arise. These were captured on a Samsung Galaxy S10+ cellphone's Voice Recorder application as mono WAV files with a sample rate of 44.1 kilohertz (kHz) and with 16-bit Pulse Code Modulation (PCM) encoding.

Disabling Interpolation

Each recording was imported into Adobe Audition to view its waveform. The software provides an automatic smoothing preset which applies a crossfade interpolation effect to any splice that is made within the workspace. This feature is enabled upon creation of any new Audition session file.

The goal of this experiment was to determine if splices could be detected after being compressed, making it imperative that the controlled edits made to each original file connected the butted ends cleanly, without adulteration. A crossfade could obscure the exact sample point of the splice and potentially interfere with the accuracy of the detection, rendering the dataset unreliable. As a result, this feature was disabled.

Trimming Impulses

It was found within the waveform that, due to the nature of the medium it was captured on, an amplitude impulse was present at the beginning and end of every file. Each recording required the record button to be pressed twice to start and stop the recording process. This left a noticeable volume spike just after capture began and just before it ended, especially in contrast to the low-level room noise these impulses surrounded. To maintain the desired amplitude consistency and avoid false detections, these impulses were removed from each and re-saved with the same WAV file parameters to provide the final uncompressed sample set.

Splicing Audio

For each of the ten original WAV files, five butt-splice edits were made in Audition. The areas removed were deleted across the time domain from the waveform in the software's audio editing window to create the artificial jumps. The edited files were organized with the title format *File #-Splice #*. For example, splice 5 of file 2 was titled 2-5.

Figure 1: Area selected before deletion in file 1-1.wav

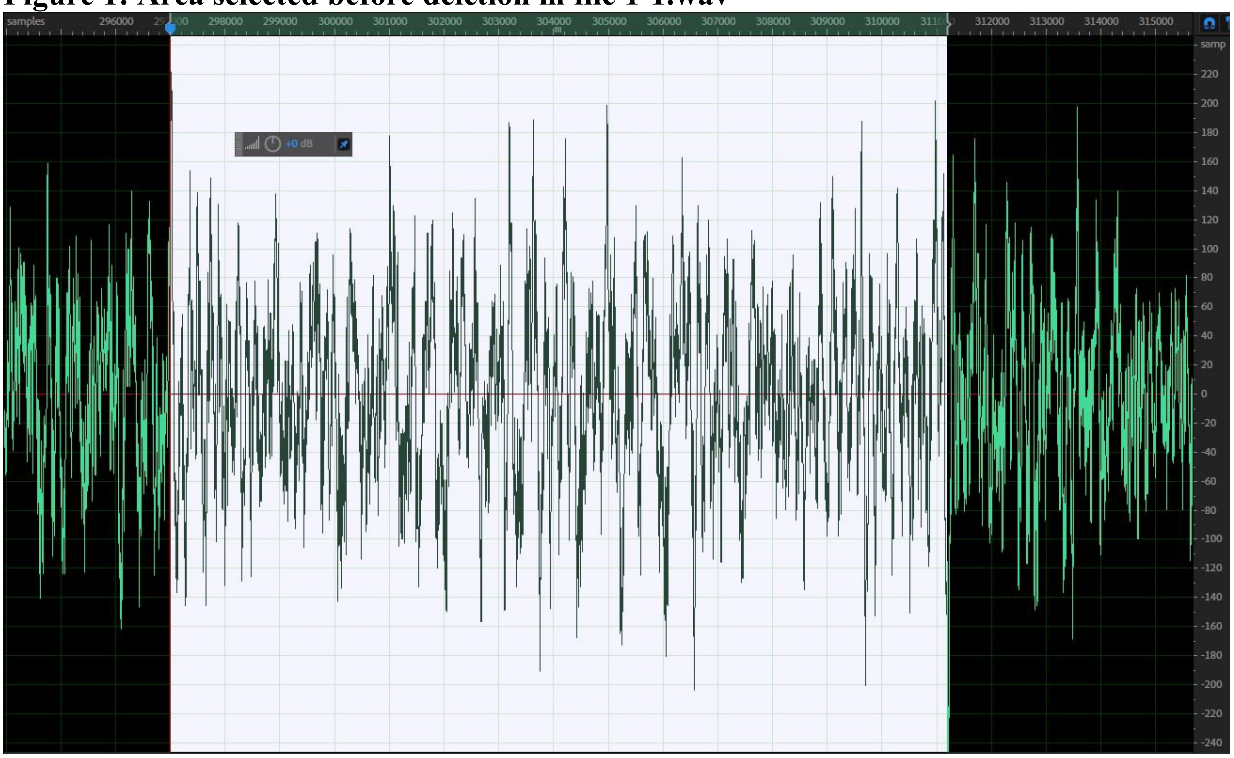
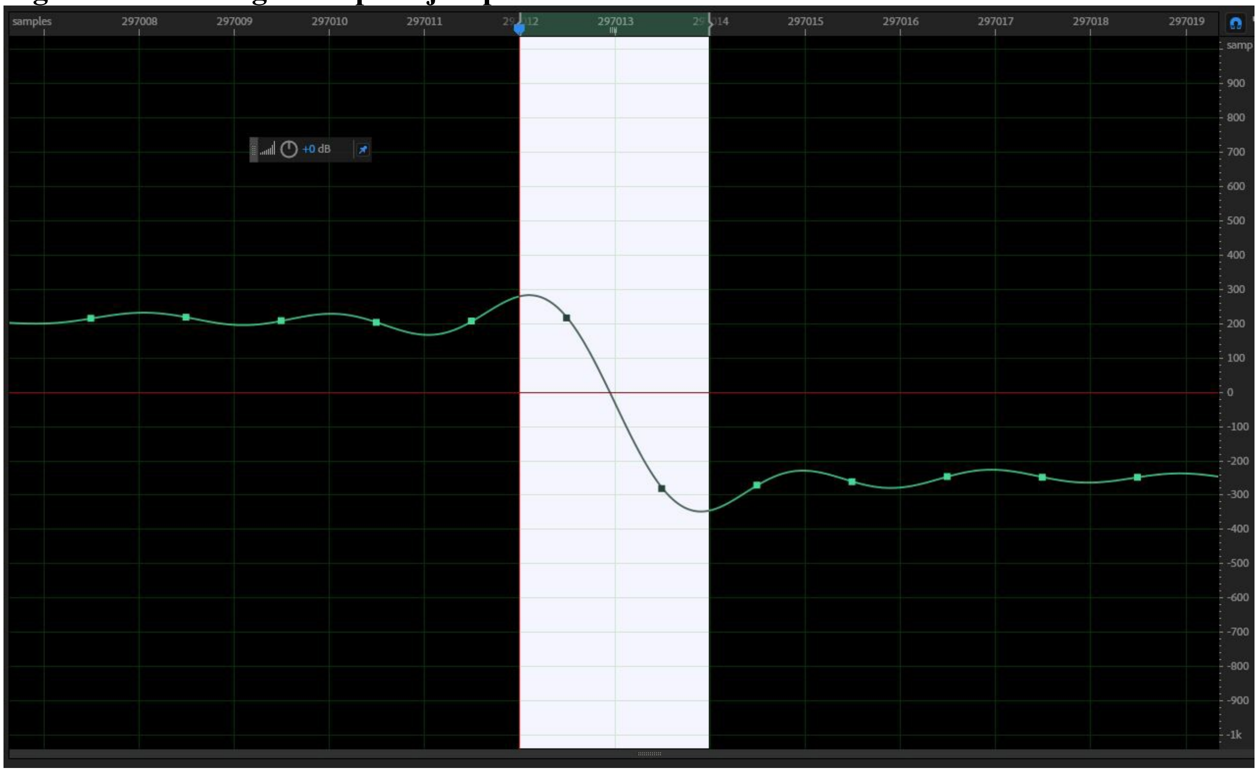


Figure 2: Resulting butt-splice jump after deletion in file 1-1.wav



To determine which splice values might influence detection, the number that was removed needed to remain consistent. This was achieved by deleting the same relative number of QLs from the five splices across all original files, the number decreasing with each subsequent splice. The highest natural jump of the original files was found by using Cooper's algorithm.

Table 3: Splice values

Splice	Area Removed
1	The area between the waveform's highest QL sample and lowest QL sample to make the highest possible jump that could be artificially created when merged.
2	An area with a slightly lower QL difference than Splice 1.
3	An area with a slightly lower QL difference than Splice 2.
4	A small area that was still large enough for the QL difference between the merged samples to be slightly higher than the QL difference of the highest natural jump.
5	An area small enough for the QL difference between the merged samples to be slightly lower than the QL difference of the highest natural jump.

After a splice was made, a new WAV file was saved with the same settings as its original (44.1 kHz/16-bit PCM). In total, these alterations produced 50 WAV files that established a control with which to measure the detection accuracy for the lossy compressed versions that would follow.

Compressing Spliced Files

FFmpeg's lossy transcoding feature was used to compress the edited WAVs into three lossy iterations (AAC, MP3, and WMA) at four different bitrates (32, 64, 128, and 256 kilobits per second or kbps).

The commands used to transcode the edited WAV files followed the structure of:

ffmpeg -i *Original*.wav -b:a *BitRate# File#-Splice#-Compression-Bitrate.extension*

For example, the command that rendered the 256kbps MP3 of file 1, splice 1 was:

ffmpeg -i 1-1.wav -b:a 256000 1-1-MP3-256.mp3

This process rendered 50 files per bitrate, which made 200 files per compression type, ultimately making a total of 600 lossy compressed files.

Running MATLAB Script

The MATLAB script was composed of several lines of code that needed to be input in sequential order to carry out their intended function.

- Audio selection from containing folder, targeting the file extensions being examined.

[name1,path1]=uigetfile({'*.aac;*.wav;*.mp3;*.wma;'}),

- Loading audio for detection.

[x,fs]=audioread(name1);

- Identifying the first and second derivative within the waveform.

x1=abs(diff(x));

x2=abs(diff(x1));

- Detecting the highest value of the two derivatives.

[a1,b1]=max(x1);

[a2,b2]=max(x2);

- Reporting the highest detected amplitude sample.

mes1=(['1st derivative butt-splice detected at sample # ',num2str(b1),',

Level1=',num2str(a1)]); disp(mes1);

mes2=(['2nd derivative butt-splice detected at sample # ',num2str(b2),',

Level2=',num2str(a2)]); disp(mes2);

For each of the 660 files (10 original WAV, 50 edited WAV, and 600 edited lossy) processed through the script, a PNG image was rendered to showcase the results (Figures 3 and 4 below). The key results displayed in these images included:

1. A visual representation of the entire waveform and the location of the detected sample where the highest jump occurred in relation.
2. The numerical value of the two consecutive sample points (K, K+1) where the highest detected jump occurred.
3. The QL amplitude of the two detected sample points and the difference between them in QLs as an absolute value.

Figure 3: MATLAB detection of highest jump for file 1-1.wav

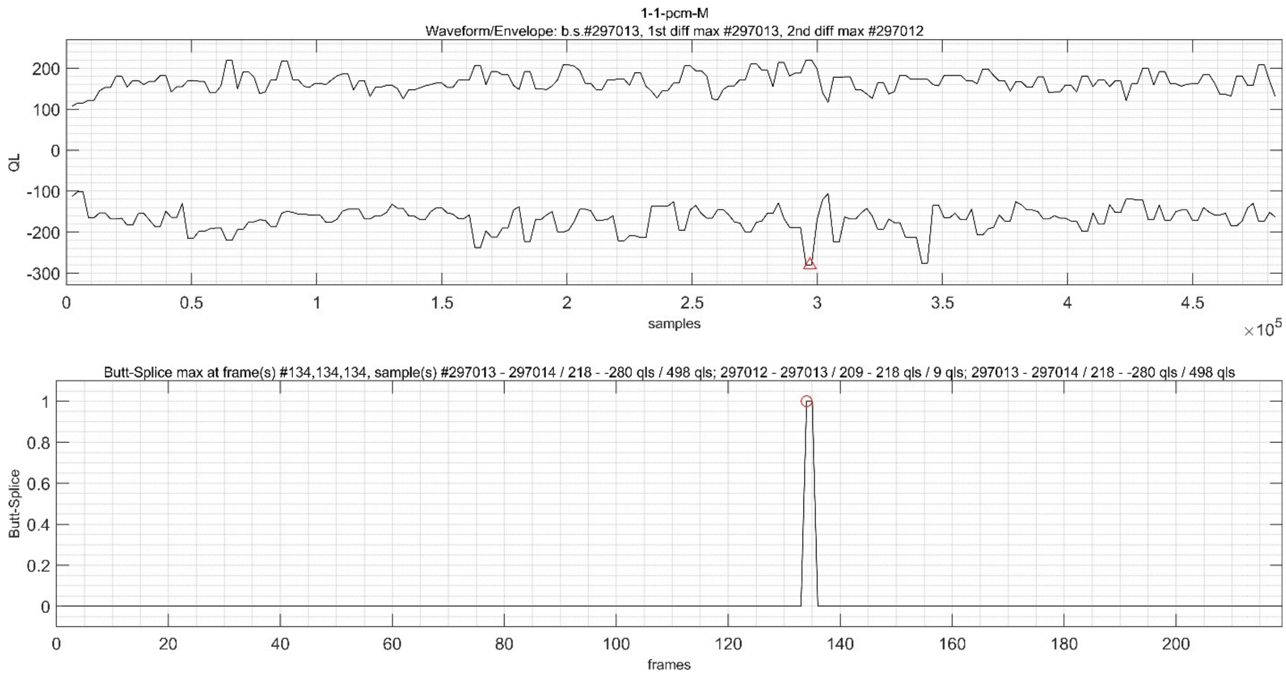
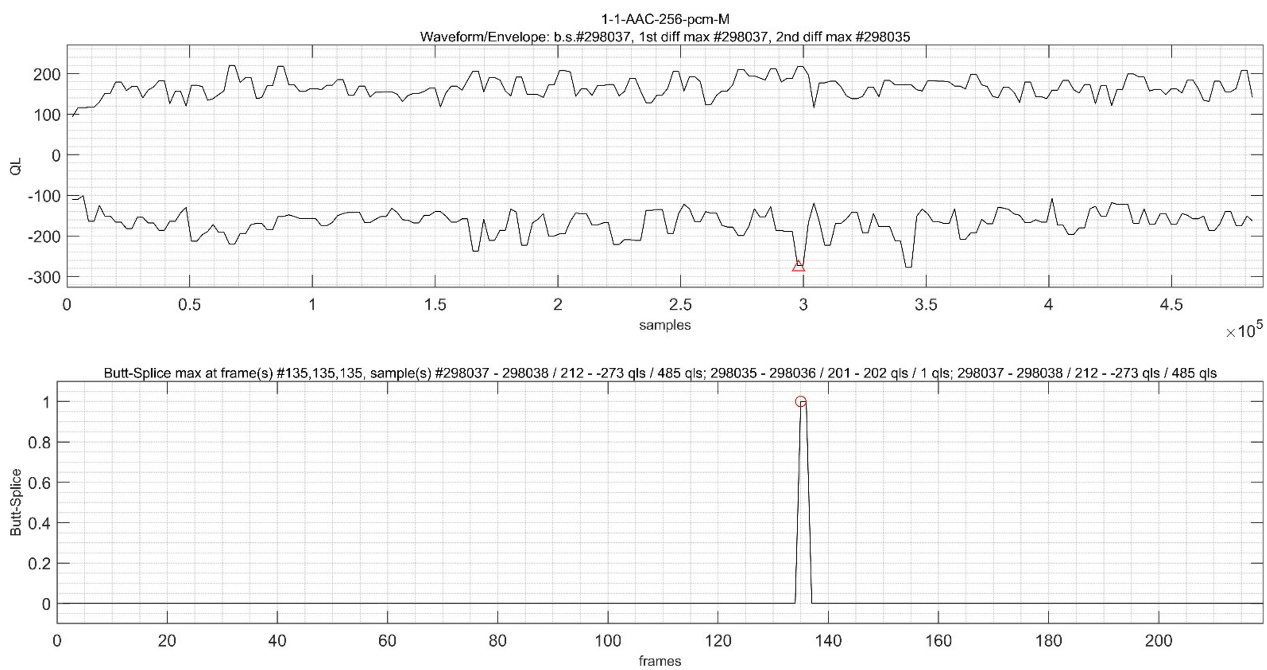


Figure 4: MATLAB detection of highest jump for file 1-1-AAC-256.aac



CHAPTER III

RESULTS

After processing, the data for all 660 files was entered into a master Excel spreadsheet to compare how the various encoding differences affected detection. As an example, below is the data for File 4. The full accounting of all files can be found in the Appendix.

Table 4: Data for file 4, uncompressed

File	Original				Splice	WAV								
	Highest Natural Jump					Area Removed					Highest Jump Detected			
	S*	QL1*	QL2	D*		S1	S2	QL1	QL2	D	S	QL1	QL2	D
4	74563	42	23	19	1	290482	292729	151	-129	280	290482	149	-129	278
					2	292393	292729	59	-129	188	292393	60	-129	189
					3	292664	292729	-54	-129	75	292664	-52	-129	77
					4	292682	292729	-96	-129	33	292682	-97	-129	32
					5	292722	292729	-114	-129	15	74563	42	23	19
*S = time domain location in samples														
*QL = amplitude quantization levels														
*D = QL difference between samples (absolute value)														

Table 5: Data for file 4, compressed

Splice	Bitrate	AAC				MP3				WMA			
		Highest Jump Detected											
		S	QL1	QL2	D	S	QL1	QL2	D	S	QL1	QL2	D
1	32	291506	82	-48	130	290482	54	-42	96	292530	47	-17	64
	64	291506	115	-89	204	290482	96	-81	177	292530	70	-56	126
	128	291506	144	-126	270	290482	129	-111	240	292530	139	-115	254
	256	291506	145	-126	271	290482	136	-116	252	292530	136	-116	252
2	32	293417	-39	-62	23	292393	1	-65	66	294441	-13	-53	40
	64	293417	20	-87	107	292393	23	-100	123	294441	12	-72	84
	128	293417	51	-124	175	292393	48	-114	162	294441	52	-122	174
	256	293417	53	-123	176	292393	51	-120	171	294441	51	-121	172
3	32	293688	-81	-106	25	292664	-56	-73	17	165466	35	18	17
	64	293688	-66	-111	45	292664	-71	-111	40	294712	-68	-111	43
	128	293688	-53	-131	78	292664	-55	-118	63	294712	-56	-125	69
	256	293688	-53	-126	73	292664	-56	-125	69	294712	-55	-125	70
4	32	66386	-17	-32	15	65346	-8	-20	12	165466	35	18	17
	64	293706	-102	-125	23	292682	-98	-115	17	135687	11	28	17
	128	293706	-95	-124	29	292682	-93	-120	27	294730	-98	-129	31
	256	293706	-97	-128	31	292682	-99	-127	28	294730	-98	-128	30
5	32	301749	-18	-36	18	65346	-8	-20	12	165467	35	18	17
	64	311006	-34	-38	4	300725	-12	-29	17	135687	11	28	17
	128	311006	-39	-44	5	19608	-45	-60	15	257540	48	65	17
	256	311006	-39	-43	4	19608	-47	-63	16	302773	-10	-27	17

Zero-Level Padding Offset

Before this data could be properly analyzed, an offset needed to be applied with consideration to zero-level padding, a known consequence of the compression process where silent samples are added to the beginning of a file. Otherwise, what would appear to be an inaccurately detected sample point may not actually be, resulting in many false positives.

It became clear that FFmpeg's compression encoding eliminates zero padding in MP3 files as the detected sample and QL of the initial uncompressed area removed consistently matched. As such, only AAC and WMA compression types needed an offset applied.

Unlike the MP3 files, these codecs show a consistently inaccurate report of the detected sample. However, if the correct sample point (S1 of the area removed from the original WAV) is subtracted from the incorrectly detected sample point, a persistent number of samples being added is revealed.

After returning the same number of samples being added to dozens of files, it was determined that the AAC files required an offset of 1024 samples and the WMA files an offset of 2048 samples.

Table 6: AAC and WMA offsets for file 4

Splice	Bitrate	AAC		WMA	
		Highest Jump Detected			
		S	O*	S	O
1	32	291506	290482	292530	290482
	64	291506	290482	292530	290482
	128	291506	290482	292530	290482
	256	291506	290482	292530	290482
2	32	293417	292393	294441	292393
	64	293417	292393	294441	292393
	128	293417	292393	294441	292393
	256	293417	292393	294441	292393
3	32	293688	292664	165466	163418
	64	293688	292664	294712	292664
	128	293688	292664	294712	292664
	256	293688	292664	294712	292664
4	32	66386	65362	165466	163418
	64	293706	292682	135687	133639
	128	293706	292682	294730	292682
	256	293706	292682	294730	292682
5	32	301749	300725	165467	163419
	64	311006	309982	135687	133639
	128	311006	309982	257540	255492
	256	311006	309982	302773	300725
O = sample detected accounting for zero offset					

Errors

With the actual sample point being detected for each compressed file known, identification of real errors could commence. Theoretically, this detection should identify the exact sample where the removed area begins in the initially manipulated WAV files. When a result diverged from this expectation, it was labeled as an error.

Table 7: Errors for file 4

Splice	WAV		Bitrate	AAC		MP3		WMA	
	Highest Jump Detected			Highest Jump Detected					
	S	D		S	D	S	D	S	D
1	290482	278	32	290482	130	290482	96	290482	64
			64	290482	204	290482	177	290482	126
			128	290482	270	290482	240	290482	254
			256	290482	271	290482	252	290482	252
2	292393	189	32	292393	23	292393	66	292393	40
			64	292393	107	292393	123	292393	84
			128	292393	175	292393	162	292393	174
			256	292393	176	292393	171	292393	172
3	292664	77	32	292664	25	292664	17	163418	17
			64	292664	45	292664	40	292664	43
			128	292664	78	292664	63	292664	69
			256	292664	73	292664	69	292664	70
4	292682	32	32	65362	15	65346	12	163418	17
			64	292682	23	292682	17	133639	17
			128	292682	29	292682	27	292682	31
			256	292682	31	292682	28	292682	30
5	74563	19	32	300725	18	65346	12	163419	17
			64	309982	4	300725	17	133639	17
			128	309982	5	19608	15	255492	17
			256	309982	4	19608	16	300725	17

Thresholds

With errors occurring in the same areas of all ten files, a trend for inaccurate detection could be determined relating to bitrate, compression type, and splice value.

Errors Per Bitrate

It can be observed that as the bitrate decreased, so did the accuracy of detection. Specifically, 35.3% of 32kbps files reported errors in contrast to 22% of 256kbps files.

Table 8: Errors per bitrate

BITRATE	SPLICE	ERROR	TOTAL	ERROR %	TOTAL %	MEAN #	SD
32	1	0	30	0	35.33%	10.6	11.3
	2	0	30	0			
	3	7	30	23.33			
	4	16	30	53.33			
	5	30	30	100			
64	1	0	30	0	27.33%	8.2	11.2
	2	0	30	0			
	3	4	30	13.33			
	4	7	30	23.33			
	5	30	30	100			
128	1	0	30	0	23.33%	7	11.6
	2	0	30	0			
	3	1	30	3.33			
	4	4	30	13.33			
	5	30	30	100			
256	1	0	30	0	22%	6.6	11.8
	2	0	30	0			
	3	0	30	0			
	4	3	30	10			
	5	30	30	100			

Figure 5: Total errors per bitrate

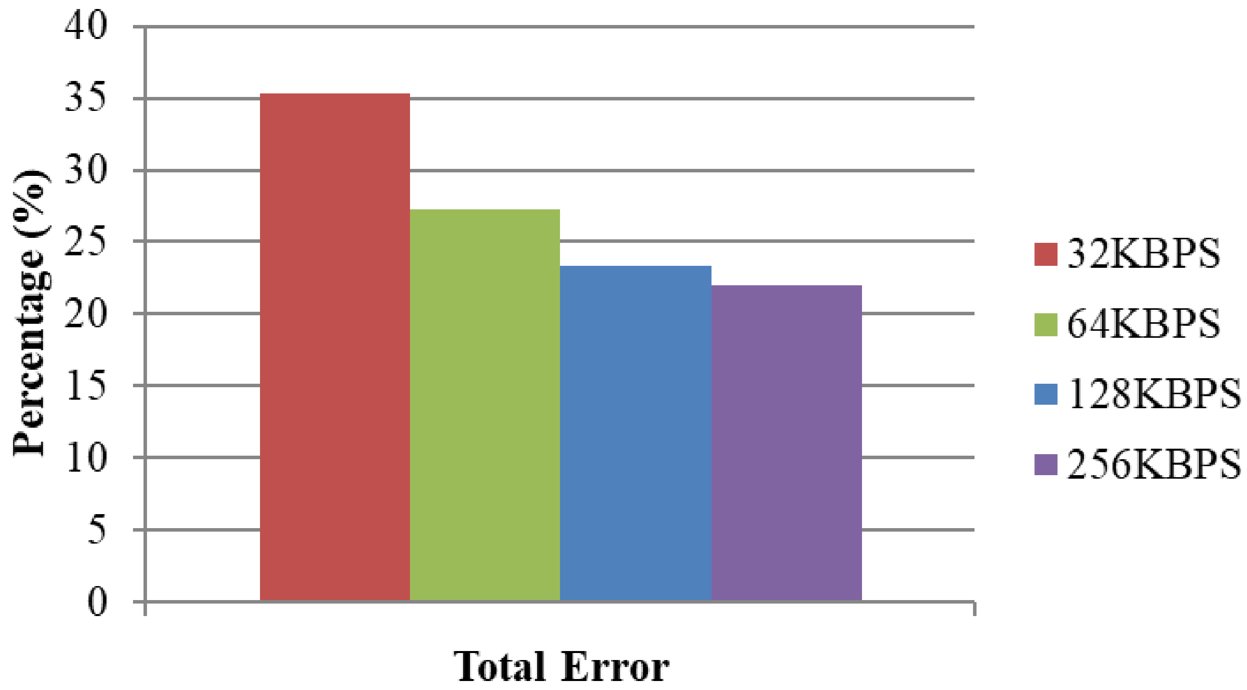
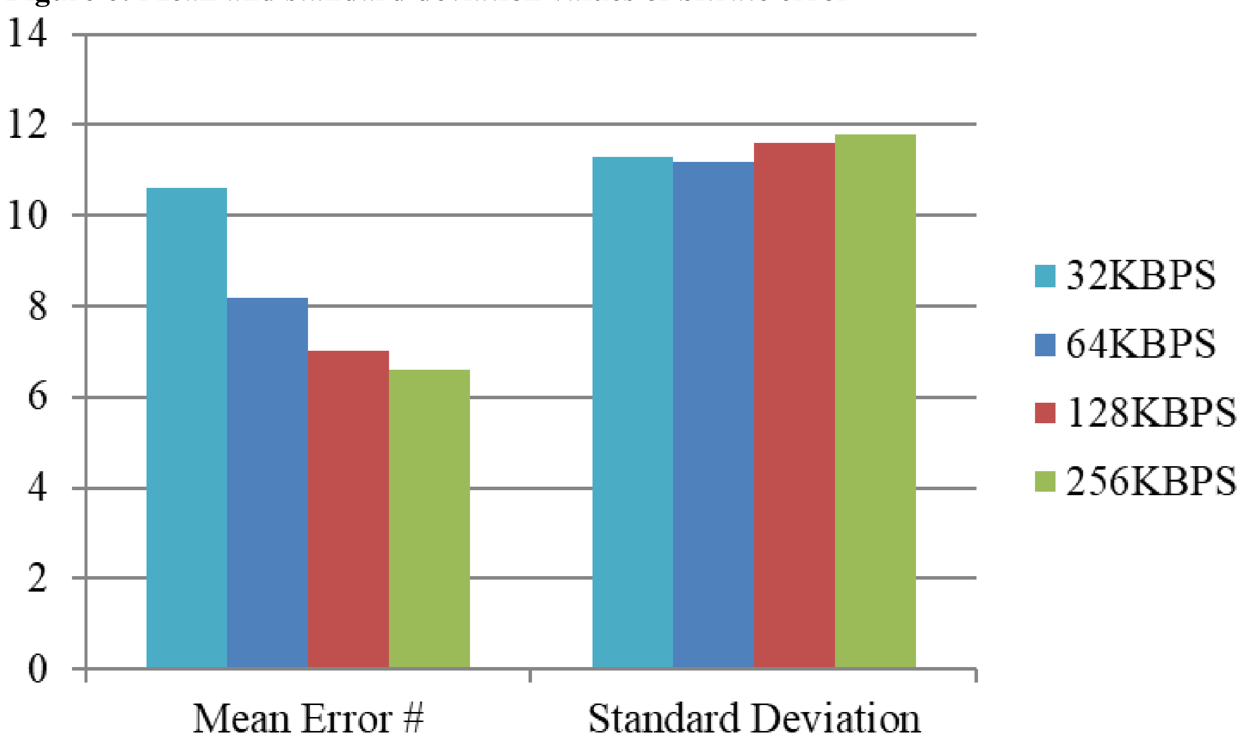


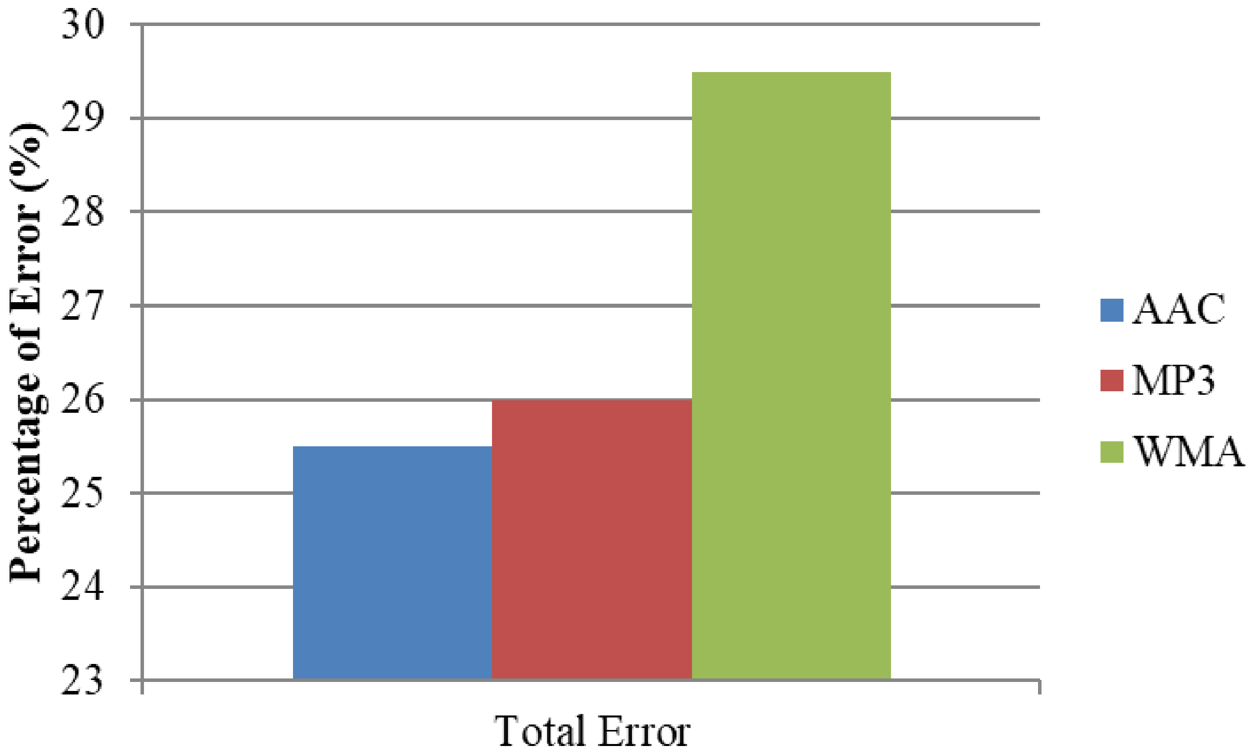
Figure 6: Mean and standard deviation values of bitrate error



Total Errors Per Compression Type

All compression types had a similar level of error at high bitrates and splice values but started to differ as they decreased. As the disparities became more pronounced, it was apparent that AAC is the least destructive type of compression with MP3 trailing close behind and WMA is the most destructive.

Figure 7: Total errors per compression type



Errors Per Compression Type in Relation to Bitrate and Splice Value

As the goal of this research was to determine the effect compression has on splice detection, the occurrence of errors in each compression type was compared in relation to the bitrate and splice value thresholds to provide further insight into how these factors influence detection.

Bitrate

Table 9: Errors per compression type by bitrate

COMP	BITRATE	ERROR	TOTAL	ERROR %	TOTAL %	MEAN #	SD
AAC	32	16	50	32	25.5	12.75	2.04
	64	13	50	26			
	128	11	50	22			
	256	11	50	22			
MP3	32	17	50	34	26	13	2.44
	64	13	50	26			
	128	11	50	22			
	256	11	50	22			
WMA	32	20	50	40	29.5	14.75	3.34
	64	15	50	30			
	128	13	50	26			
	256	11	50	22			

Figure 8: Errors per compression type by bitrate

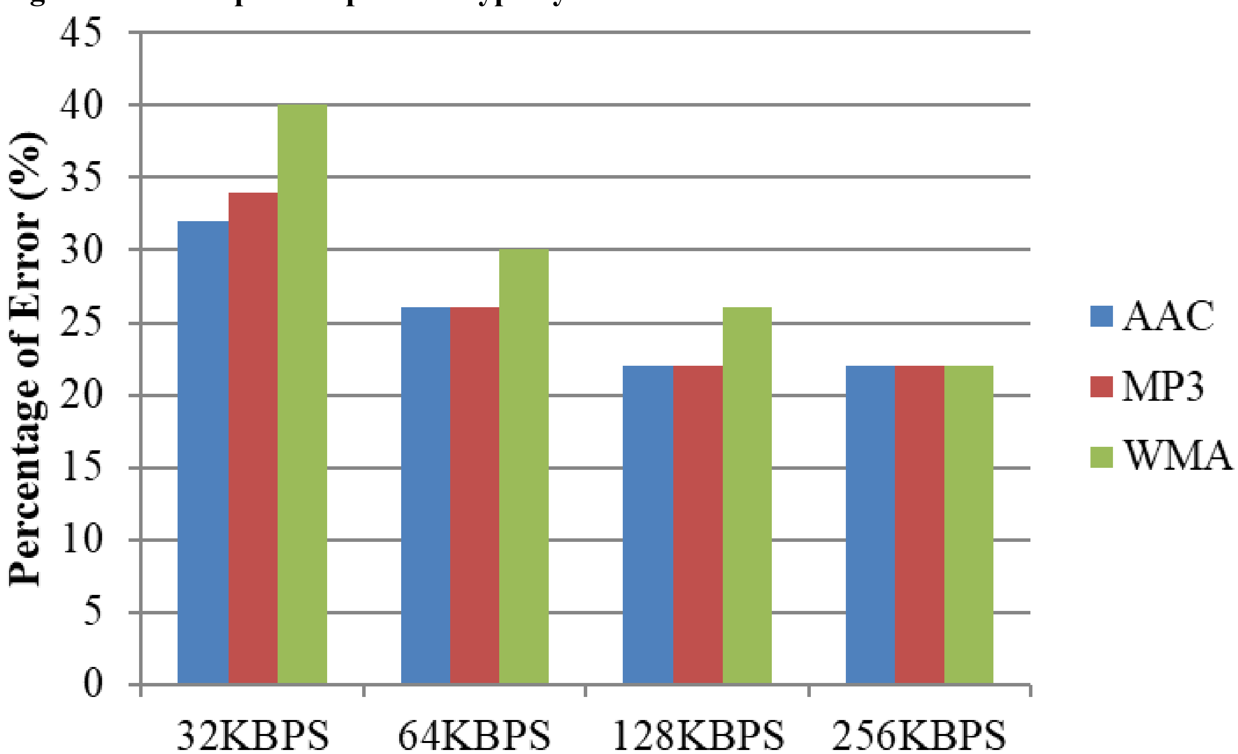
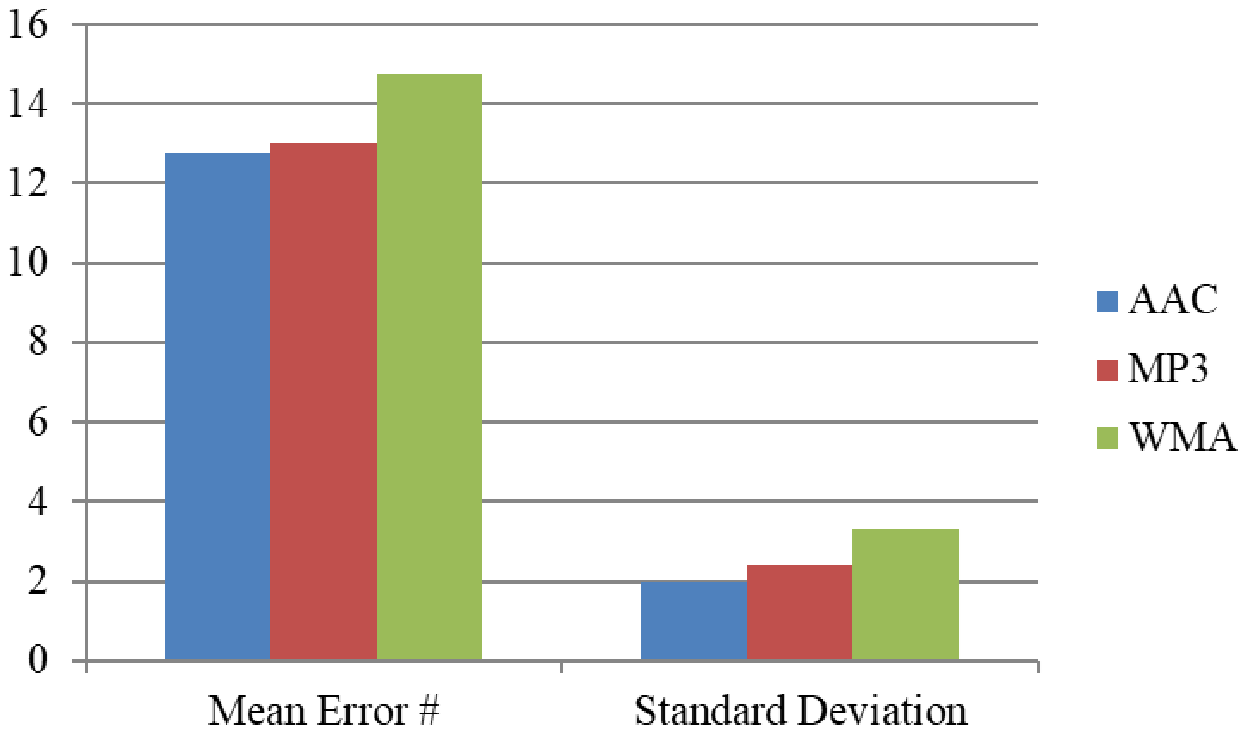


Figure 9: Mean and standard deviation values of compression type errors by bitrate



Splice Value

Table 10: Errors per compression type by splice value

COMP	SPLICE	ERROR	TOTAL	ERROR %	TOTAL %	MEAN #
AAC	1	0	40	0%	25.50%	10.2
	2	0	40	0%		
	3	3	40	7.50%		
	4	8	40	20%		
	5	40	40	100%		
MP3	1	0	40	0%	26%	10.4
	2	0	40	0%		
	3	3	40	7.50%		
	4	9	40	22.50%		
	5	40	40	100%		
WMA	1	0	40	0%	29.50%	11.8
	2	0	40	0%		
	3	6	40	15.00%		
	4	13	40	32.50%		
	5	40	40	100%		

Figure 10: Errors per compression type by splice value

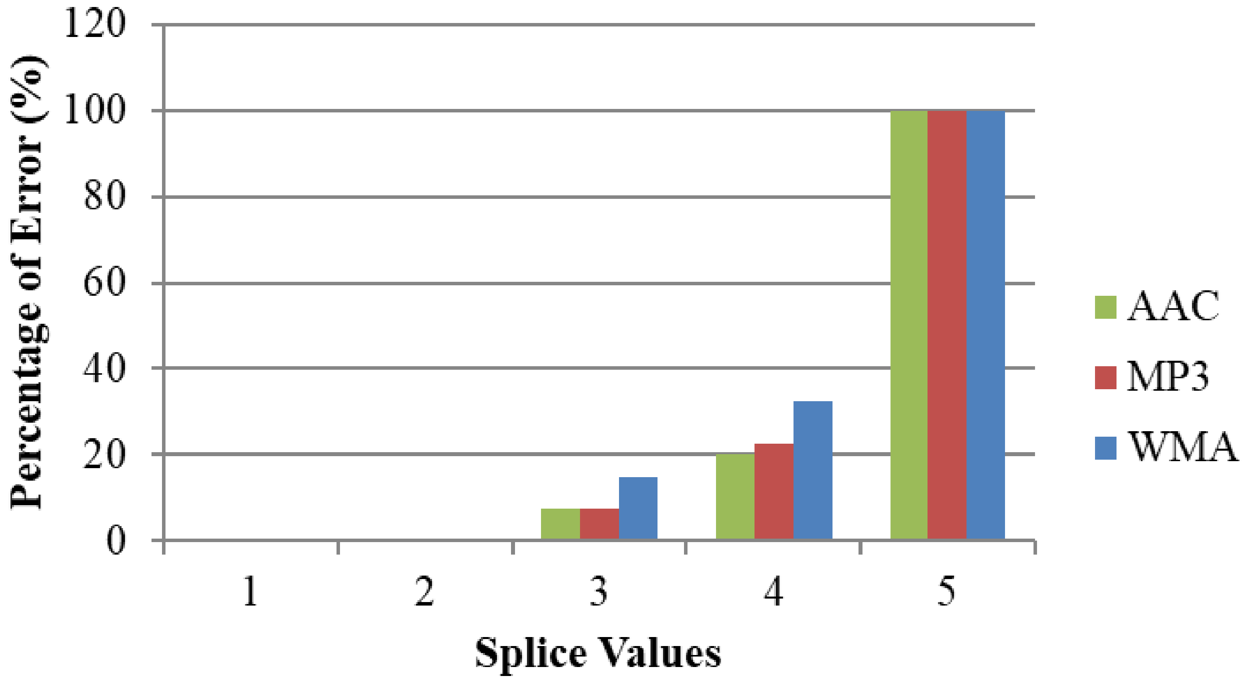
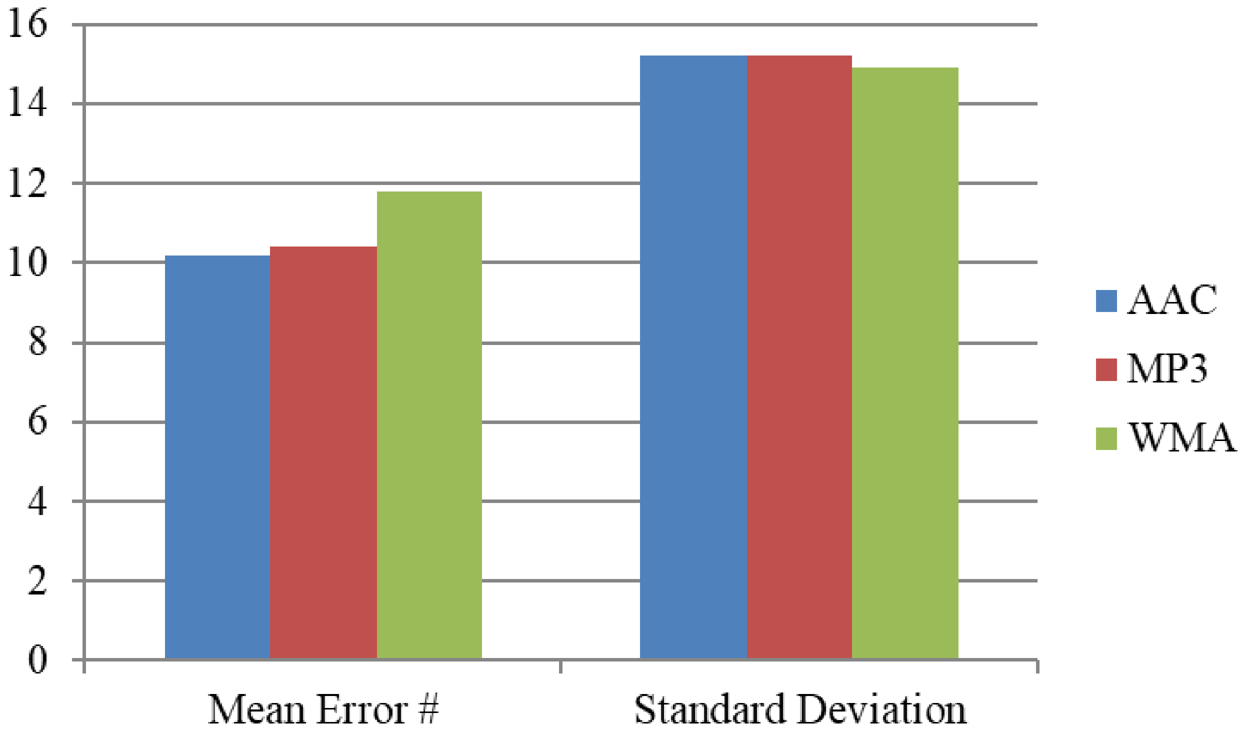


Figure 11: Mean and standard deviation values of compression type errors by splice value



Errors Per Splice Value

The QL disparity of each splice had a direct correlation to the percentage of errors in the detection. Figure 7 displays the relationship: as the QL percent difference decreased, so did the detection accuracy. This implies that the greater amplitude jump a splice contains, the easier it is to detect, while a smaller jump is more likely to be masked by compression.

This explains why all splice 5 files reported errors, as it was the one splice value that went below the jump value of the original file. Thus, the detected highest jump was identified as the natural jump, as the edit value was smaller in amplitude.

Table 11: Errors per splice value

SPLICE	FILE	SIZE INCREASE						ERRORS DETECTED					
		OG	EDIT	INCREASE %	MEAN %	MEAN #	SD	ERRORS	TOTAL	ERROR %	TOTAL %	MEAN #	SD
1	1	86	502	583.72%	1015.05%	295.4	210.4	0	13	0%	0%	0	0
	2	142	845	595.07%				0	13	0%			
	3	23	313	1360.87%				0	13	0%			
	4	19	280	1473.68%				0	13	0%			
	5	20	175	875%				0	13	0%			
	6	16	181	1131.25%				0	13	0%			
	7	14	148	1057.14%				0	13	0%			
	8	17	195	1147.06%				0	13	0%			
	9	18	156	866.67%				0	13	0%			
	10	15	159	1060%				0	13	0%			
2	1	86	377	438.37%	666.75%	204.6	162.7	0	13	0%	0%	0	0
	2	142	620	436.62%				0	13	0%			
	3	23	232	1008.70%				0	13	0%			
	4	19	188	989.47%				0	13	0%			
	5	20	112	560%				0	13	0%			
	6	16	135	843.75%				0	13	0%			
	7	14	74	528.57%				0	13	0%			
	8	17	98	576.47%				0	13	0%			
	9	18	103	572.22%				0	13	0%			
	10	15	107	713.33%				0	13	0%			
3	1	86	172	200%	366.89%	110.5	88.9	4	13	30.77%	9.23%	1.2	2.27
	2	142	351	247.18%				7	13	53.84%			
	3	23	140	608.70%				0	13	0%			
	4	19	75	394.74%				1	13	7.7%			
	5	20	65	325%				0	13	0%			
	6	16	80	500%				0	13	0%			
	7	14	50	357.14%				0	13	0%			
	8	17	46	270.59%				0	13	0%			
	9	18	67	372.22%				0	13	0%			
	10	15	59	393.33%				0	13	0%			

Table 11: Continued

SPLICE	FILE	SIZE INCREASE						ERRORS DETECTED					
		OG	EDIT	INCREASE %	MEAN %	MEAN #	SD	ERRORS	TOTAL	ERROR %	TOTAL %	MEAN #	SD
4	1	86	77	89.53%	174.42%	51.7	40.8	12	13	92.3%	23.08%	3	3.66
	2	142	165	116.12%				7	13	53.8%			
	3	23	60	260.87%				2	13	15.4%			
	4	19	33	173.68%				4	13	30.7%			
	5	20	33	165%				3	13	23.%			
	6	16	29	181.25%				0	13	0%			
	7	14	30	214.28%				1	13	7.7%			
	8	17	24	141.17%				1	13	7.7%			
	9	18	34	188.88%				0	13	0%			
	10	15	32	213.33%				0	13	0%			
5	1	86	32	37.21%	61.94%	22.2	26.2	13	13	100%	100%	13	0
	2	142	98	69.01%				13	13	100%			
	3	23	20	86.96%				13	13	100%			
	4	19	15	78.95%				13	13	100%			
	5	20	9	45%				13	13	100%			
	6	16	14	87.50%				13	13	100%			
	7	14	9	64.29%				13	13	100%			
	8	17	5	29.41%				13	13	100%			
	9	18	11	61.11%				13	13	100%			
	10	15	9	60%				13	13	100%			
OG = natural jump splice													
EDIT = edited splice jump													
SD = standard deviation													

Figure 12: Mean splice error by mean splice value increase

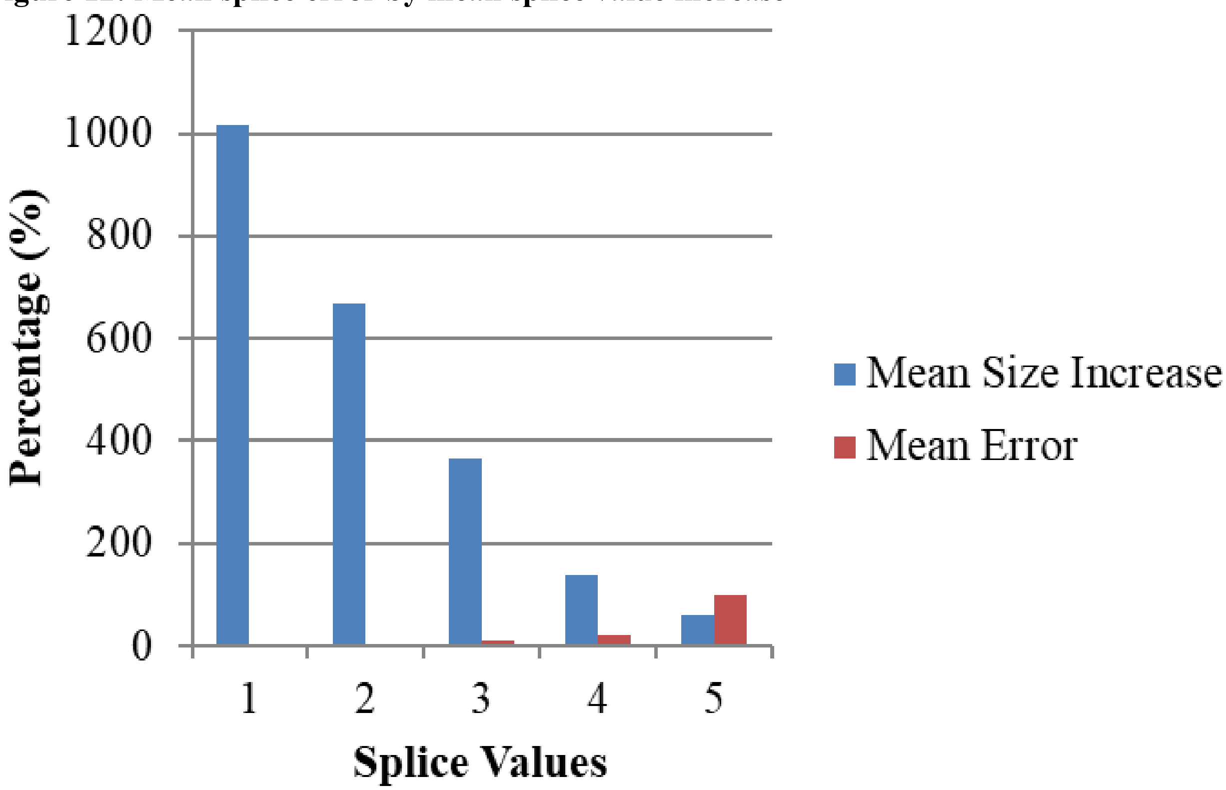


Figure 13: Mean and standard deviation values of splice value increase

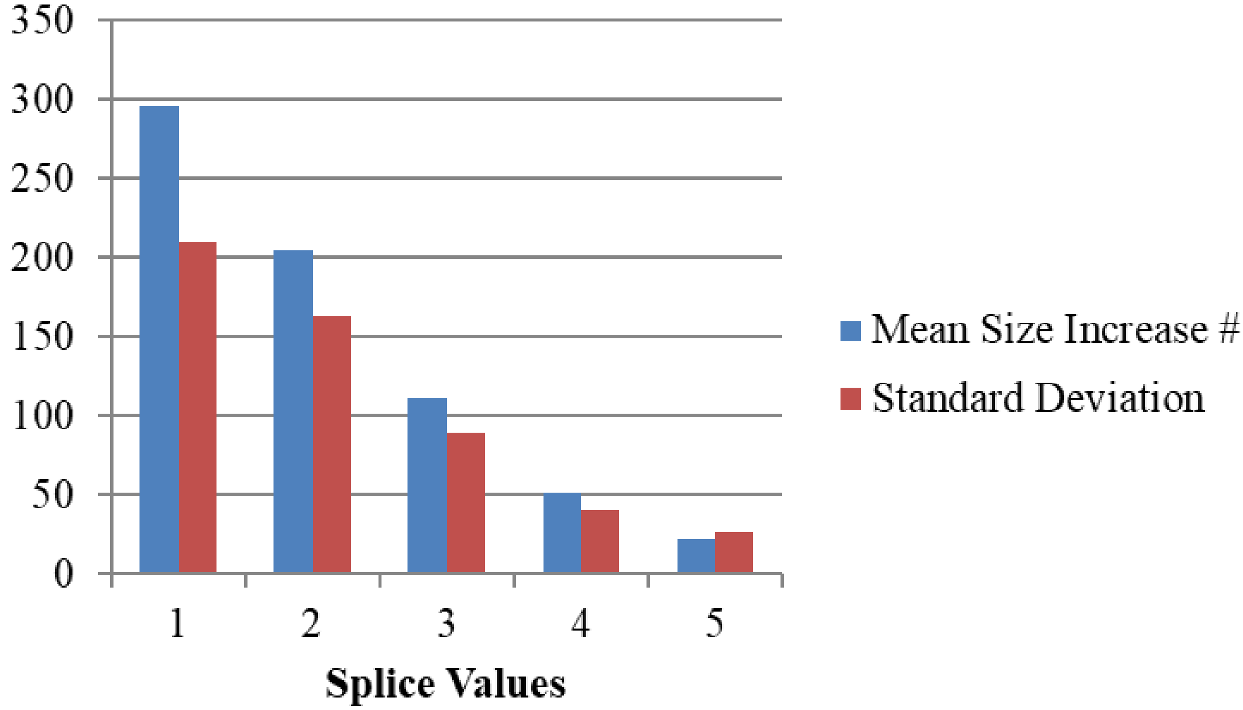
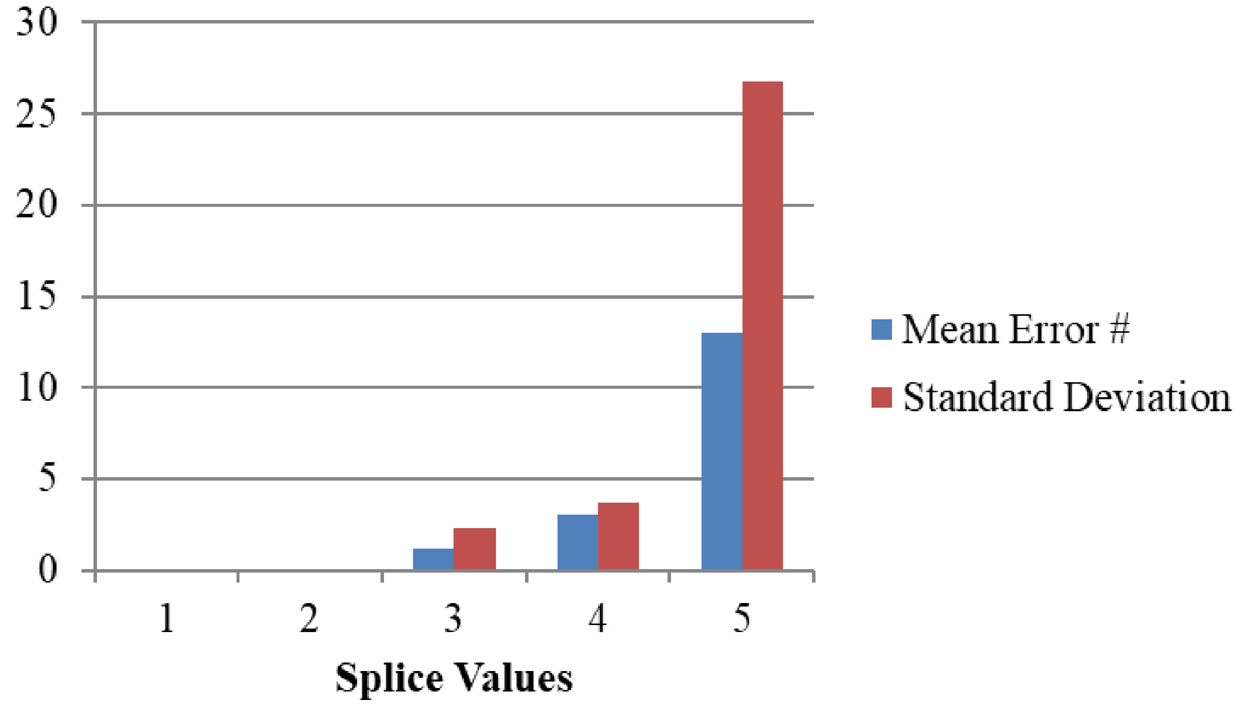


Figure 14: Mean and standard deviation values of splice value error



Conclusions

The data collected above demonstrates that all three factors being analyzed (bitrate, compression type, and splice value) will influence the detection of an accurate splice sample. Of the compression types and bitrates tested, the most accurate detections occurred with AAC at 256kbps. The following conclusions can be drawn based on the results.

Bitrate

- A decrease in lossy compression bitrate will result in an increase in detection errors.
- A bitrate below 64kbps will contribute to erroneous results provided that the area being removed isn't significantly larger than the highest natural jump.
- A bitrate above 128kbps will return accurate results provided that the area being removed isn't of similar size with the highest natural jump.

Compression Type

- Detection is least affected by AAC compression.
- Detection is most affected by WMA compression.
- Detection with MP3, while less accurate than AAC, is still more robust than WMA.

Splice Value

- A decrease in the QL disparity associated with a butt-splice will yield less reliable detection results.
- If the artificial amplitude jump is above but near to the highest natural jump, the results will be less reliable.
- If the artificial jump is less than a 100% increase from the highest natural jump, detection will be inaccurate.

CHAPTER IV

DISCUSSION

The five questions this study posed in Chapter I can be re-assessed with the conclusions provided by the results above.

Goal Appraisal

Does lossy compression mask the detection of butt-splice edits?

Undoubtedly, yes. It was clearly shown that certain lossy compression will mask detection. However, the mere fact that a file is compressed does not mean it cannot be detected. The level of degradation is an essential factor to consider. For example, a file with a bitrate of 128kbps or above will require other thresholds to be met to report errors.

Do different lossy compressions have different effects on detection?

Yes, each of the three lossy compression types had different effects on detecting an accurate sample. Their individual algorithms process the files in proprietary ways that make determining which codecs will have a greater or lesser influence on detection unpredictable. It is beyond the scope of this study to decipher why a specific effect is occurring, but report that they do in fact have an effect.

Do different bitrates have different effects on detection?

Yes. The lower the bitrate, the more unreliable the detected sample becomes. It was determined that below 64kbps, results are highly suspect.

Do different splice values have different effects on detection?

Yes. In fact, this appeared to be the most crucial element in the accuracy of detection. Regardless of any other factor, if the amplitude jump introduced by an edit is below that file's highest natural jump, detection will be inaccurate

What are the thresholds at which edits are no longer detectable?

The threshold determinations for each of the three factors are as follows:

Bitrate: Errors are more likely to occur with a lower bitrate. Specifically, a bitrate below 64kbps and especially 32kbps will return more errors than 128 or 256.

Compression Type: While there is not a specific threshold that could be determined for this factor, the study was able to identify that the AAC codec returned the least amount of errors.

Splice Value: Errors are far more likely to occur the smaller the artificial QL jump becomes. Anything below the highest natural jump will not return accurate results.

Future Research

The research conducted for this study, while a successful preliminary look, only represents a small portion of data that could be collected on this subject. Possible areas that could be considered for future research might include:

- A larger preliminary sample size than the ten examined here would be beneficial to solidify the findings beyond the trends this study drew its conclusions from.
- Expanding the number of codecs being tested. Though common, the three compression types used in this study are not a full accounting. For instance, OGG Vorbis may be an enlightening codec to incorporate into future studies.
- Likewise, it would be interesting to experiment with a greater array of QL splice values. Perhaps a more in-depth study could measure the detection differences at minute level, such as a 1 QL difference above or below the highest natural jump.
- Increasing the number of recording devices beyond the one tested here.

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[3] Cooper, Alan J. *Detection of Copies of Digital Audio Recordings for Forensic Purposes* PhD thesis, Open University, Milton Keynes, UK, 2006. AAFS 70th Annual Scientific Meeting, Seattle, Washington, 2018.

[4] Grigoras C., and Smith J.M. *Audio Enhancement and Authentication* Siegel JA and Saukko PJ Encyclopedia of Forensic Sciences, 2nd Edition, pp. 315-326. Waltham Academic Press. 2013.

[5] Grigoras, C., Smith, J.M. *Time Domain Analysis of Lossy Compression Decoding Artifacts*

[6] *SWGDE Best Practices for Digital Audio Authentication* Version: 1.3 (September 20, 2018)

APPENDIX

Table 12: Master data spreadsheet

File	Original				Splice	WAV									Bitrate	AAC				MP3				WMA				OFFSET	
	Highest Natural Jump					Area Removed					Highest Jump Detected					Highest Jump Detected												AAC	WMA
	S*	QL1*	QL2	D*		S1	S2	QL1	QL2	D	S	QL1	QL2	D		S	QL1	QL2	D	S	QL1	QL2	D	S	QL1	QL2	D		
1	130025	76	-10	86	1	297013	311207	222	-280	502	297013	218	-280	498	32	298037	44	-169	213	297013	52	-112	164	299061	40	-86	126	297013	297013
															64	298037	140	-212	352	297013	159	-184	343	299061	63	-146	209	297013	297013
															128	298037	213	-268	481	297013	183	-242	425	299061	210	-267	477	297013	297013
															256	298037	212	-273	485	297013	193	-255	448	299061	195	-255	450	297013	297013
					2	311127	311207	97	-280	377	311127	107	-280	387	32	312151	19	-122	141	311127	-13	-151	138	313175	-19	-127	108	311127	311127
															64	312151	72	-213	285	311127	42	-217	259	313175	-9	-162	153	311127	311127
															128	312151	87	-248	335	311127	83	-247	330	313175	79	-253	332	311127	311127
															256	312151	103	-275	378	311127	87	-260	347	313175	89	-262	351	311127	311127
					3	311160	311207	-108	-280	172	311160	-126	-280	154	32	131029	-111	-3	108	129993	-24	53	77	132083	3	85	82	130005	130035
															64	312184	-151	-244	93	311160	-137	-241	104	132041	-28	52	80	311160	129993
															128	312184	-126	-269	143	311160	-131	-261	130	313208	-150	-258	108	311160	311160
															256	312184	-128	-278	150	311160	-134	-272	138	313208	-133	-272	139	311160	311160
					4	311198	311207	-203	-280	77	311198	-191	-280	89	32	131029	-111	-3	108	129993	-24	53	77	132083	3	85	82	130005	130035
															64	131068	38	-48	86	130025	72	-10	82	132041	-28	52	80	130044	129993
															128	131049	80	-6	86	130025	75	-12	87	132073	79	-11	90	130025	130025
															256	312222	-193	-279	86	130025	78	-12	90	132073	79	-12	91	311198	130025
					5	311200	311207	-248	-280	32	130025	76	-10	86	32	131029	-111	-3	108	129993	-24	53	77	132083	3	85	82	130005	130035
															64	131068	38	-48	86	130025	72	-10	82	132041	-28	52	80	130044	129993
															128	131049	80	-6	86	130025	75	-12	87	132073	79	-11	90	130025	130025
															256	131029	-86	-2	84	130025	78	-12	90	132073	79	-12	91	130005	130025
2	265453	13	-129	142	1	113384	248077	431	-414	845	113384	420	-414	834	32	114408	285	26	259	113384	142	-146	288	115432	142	-146	288	113384	113384
															64	114408	336	-381	717	113384	273	-268	541	115432	273	-268	541	113384	113384
															128	114408	417	-392	809	113384	355	-355	710	115432	355	-355	710	113384	113384
															256	114408	402	-404	806	113384	381	-375	756	115432	381	-375	756	113384	113384
					2	247825	248077	206	-414	620	247825	216	-414	630	32	248849	15	-244	259	247825	43	-189	232	249873	43	-189	232	247825	247825
															64	248849	122	-312	434	247825	136	-313	449	249873	136	-313	449	247825	247825
															128	248849	201	-403	604	247825	175	-365	540	249873	175	-365	540	247825	247825
															256	248849	209	-413	622	247825	185	-384	569	249873	185	-384	569	247825	247825
					3	247986	248077	-63	-414	351	247986	-239	-414	175	32	266386	-10	-136	126	265362	-1	-120	119	267410	-1	-120	119	265362	265362
															64	266386	30	-101	131	265362	10	-124	134	267410	10	-124	134	265362	265362
															128	249010	-237	-409	172	247986	-233	-380	147	267410	-233	-380	147	247986	265362
															256	249010	-243	-416	173	247986	-248	-404	156	250034	-248	-404	156	247986	247986
					4	248065	248077	-249	-414	165	248065	-247	-414	167	32	266466	-108	-227	119	265441	19	-107	126	267489	2	-124	126	265442	265441
															64	266466	-101	-225	124	265441	8	-131	139	267489	16	-129	145	265442	265441
															128	249089	-246	-406	160	248065	-242	-383	141	267489	13	-128	141	248065	265441
															256	249089	-246	-408	162	248065	-256	-405	149	250113	-256	-405	149	248065	248065
					5	248070	248077	-316	-414	98	265446	13	-129	142	32	266471	-98	-223	125	265446	-15	-143	128	267494	2	-127	129	265447	265446
															64	266471	-98	-223	125	265446	5	-121	126	267494	13	-131	144	265447	265446
															128	266470	-3	-135	132	265446	11	-120	131	267494	11	-129	140	265446	265446
															256	266470	14	-126	140	265446	12	-127	139	267494	12	-129	141	265446	265446
3	173487	-24	-1	23	1	71967	253057	153	-160	313	71967	151	-160	311	32	72991	67	-77	144	71967	52	-58	110	74015	35	-39	74	71967	71967
															64	72991	107	-119	226	71967	105	-115	220	74015	65	-77	142	71967	71967
															128	72991	150	-155	305	71967	131	-140	271	74015	145	-147	292	71967	71967
															256	72991	152	-150	302	71967	138	-146	284	74015	136	-147	283	71967	71967
					2	252600	253057	72	-160	232	252600	42	-160	202	32	253624	-12	-103	91	252600	-24	-94	70	254648	-39	-83	44	252600	252600
															64	253624	21	-146	167	252600	8	-123	131	254648	-3	-115	112	252600	252600
															128	253624	34	-157	191	252600	29	-142	171	254648	34	-148	182	252600	252600
															256	253624	39	-161	200	252600	32	-149	181	254648	32	-150	182	252600	252600
					3	252762	253057	-20	-160	140	252762	-38	-160	122	32	253786	-78	-114	36	252762	-76	-114	38	254810	-82	-111	29	252762	252762
															64	253786	-43	-141	98	252762	-60	-138	78	254810	-61	-135	74	252762	252762
															128	253786	-40	-159	119	252762	-42	-146	104	254810	-44	-156	112	252762	252762
															256	253786	-40	-160	120	252762	-44	-154	110	254810	-44	-154	110	252762	252762
					4	253009	253057	-100	-160	60	253009	-104	-160	56	32	254033	-108	-134	26	173488	-7	15	22	175535	-29	-7	22	253009	173487
															64	254033	-107	-148	41	253009	-106	-143	37	255057	-112	-149	37	253009	253009
															128	254033	-106	-160	54	253009	-101	-149	48	255057	-106	-159	53	253009	253009
															256	254033	-106	-161	55	253009	-106	-158	52	255057	-106	-158	52	253009	253009
					5	253042	253057	-140	-160	20	173487	-24	-1	23	32	174511	-23	-3	20	173488	-7	15	22	175535	-29	-7	22	173487	173487
															64	174511	-22	1	23	173487	-23	1	24	175515	-13	-34	21	173487	173467
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															256	1024	-1	-26	25	173487	-1	-26	25	2048	-2	-26	24	0	0
4	74563	42	23	19	1	290482	292729	151	-129	280	290482	149	-129	278	32	291506	82	-48	130	290482	54	-42	96	292530	47	-17	64	290482	290482
															64	291506	115	-89	204	290482	96	-81	177	292530	70	-56	126	290482	290482
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															256	291506	145	-126	271	290482	136	-116	252	292530	136	-116	252	290482	290482
					2	292393	292729	59	-129	188	292393	60	-129	189	32	293417	-39	-62	23	292393	1	-65	66	294441	-13	-53	40	292393	292393
															64	293417	20	-87	107	292393	23	-100	123	294441	12	-72	84	292393	292393
															128	293417	51	-124	175	292393	48	-114	162	294441	52	-122	174	292393	292393
															256	293417	53	-123	176	292393	51	-120	171	294441	51	-121	172	292393	292393
					3	292664	292729	-54	-129	75	292664	-52	-129	77	32	293688	-81	-106	25	292664	-56	-73	17	165466	35	18	17	292664	163418
															64	293688	-66	-111	45	292664	-71	-111	40	294712	-68	-111	43	292664	292664
															128	293688	-53	-131	78	292664	-55	-118	63	294712	-56	-125	69	292664	292664
															256	293688	-53	-126	73	292664	-56	-125	69	294712	-55	-125	70	292664	292664
					4	292682	292729	-96	-129	33	292682	-97	-129	32	32	66386	-17	-32	15	65346	-8	-20	12	165466	35	18	17	65362	163418
															64	293706	-102	-125	23	292682	-98	-115	17	135687	11	28	17	292682	133639
															128	293706	-95	-124	29	292682	-93	-120	27	294730	-98	-129	31	292682	292682
															256	293706	-97	-128	31	292682	-99	-127	28	294730	-98	-128	30	292682	292682
					5	292722	292729	-114	-129	15	74563	42	23	19	32	301749	-18	-36	18	65346	-8	-20	12	165467	35	18	17	300725	163419
															64	311006	-34	-38	4	300725	-12	-29	17	135687	11	28	17	309982	133639
															128	311006	-39	-44	5	19608	-45	-60	15	257540	48	65	17	309982	255492
															256	311006	-39	-43	4	19608	-47	-63	16	302773	-10	-27	17	309982	300725
5	390204	-10	-30	20	1	313622	315825	77	-98	175	313622	76	-99	175	32	314646	26	-60	86	313622	21	-41	62	315670	6	-32	38	313622	313622
															64	314646	46	-83	129	313622	55	-71	126	315670	31	-56	87	313622	313622
															128	314646	75	-97	172	313622	66	-87	153	315670	70	-94	164	313622	313622
															256	314646	69	-95	164	313622	68	-92	160	315670	70	-93	163	313622	313622
					2	315759	315825	14	-98	112	315759	14	-99	113	32	316783	-14	-59	45	315759	-22	-61	39	317807	-27	-55	28	315759	315759
															64	316783	2	-83	85	315759	-7	-78	71	317807	-7	-79	72	315759	315759
															128	316783	12	-98	110	315759	9	-91	100	317807	9	-95	104	315759	315759
															256	316783	11	-99	110	315759	10	-95	105	317807	9	-95	104	315759	315759
					3	315785	315825	-33	-98	65	315785	-33	-99	66	32	316809	-52	-83	31	315785	-49	-74	25	317833	-54	-74	20	315785	315785
															64	316809	-40	-90	50	315785	-40	-87	47	317833	-42	-92	50	315785	315785
															128	316809	-32	-96	64	315785	-32	-92	60	317833	-35	-97	62	315785	315785
															256	316809	-34	-98	64	315785	-34	-98	64	317833	-34	-98	64	315785	315785
					4	315805	315825	-65	-98	33	315805	-71	-99	28	32	391263	2	21	19	390184	-6	-22	16	391763	24	8	16	390239	389715
															64	316829	-71	-94	23	315805	-69	-90	21	317853	-71	-97	26	315805	315805
															128	316829	-67	-94	27	315805	-68	-95	27	317853	-71	-98	27	315805	315805
															256	316829	-72	-99	27	315805	-71	-99	28	317853	-71	-99	28	315805	315805
					5	315818	315825	-89	-98	9	390198	-10	-30	20	32	387807	-23	-6	17	386783	-26	-11	15	388831	-23	-8	15	386783	386783
															64	391221	-11	-30	19	385486	42	27	15	388821	11	29	18	390197	386773
															128	391221	-9	-27	18	390197	-11	-28	17	387519	63	46	17	390197	385471
															256	391221	-9	-29	20	390197	-11	-30	19	392246	-11	-30	19	390197	390198

Table 12: Continued

6	683	28	44	16	1	289255	339376	93	-88	181	289255	87	-88	175	32	290279	25	-36	61	289255	29	-29	58	291303	19	-22	41	289255	289255
															64	290279	59	-65	124	289255	63	-60	123	291303	53	-52	105	289255	289255
															128	290279	86	-86	172	289255	77	-78	155	291303	82	-83	165	289255	289255
															256	290279	79	-87	166	289255	80	-82	162	291303	80	-82	162	289255	289255
					2	339112	339376	47	-88	135	339112	49	-88	137	32	340136	3	-49	52	339112	5	-42	47	341160	-5	-36	31	339112	339112
															64	340136	27	-64	91	339112	24	-61	85	341160	23	-61	84	339112	339112
															128	340136	48	-87	135	339112	39	-75	114	341160	41	-81	122	339112	339112
															256	340136	49	-85	134	339112	42	-81	123	341160	41	-81	122	339112	339112
					3	339304	339376	-8	-88	80	339304	-6	-88	82	32	340328	-31	-61	30	339304	-31	-53	22	341352	-30	-53	23	339304	339304
															64	340328	-16	-73	57	339304	-20	-68	48	341352	-19	-73	54	339304	339304
															128	340328	-4	-86	82	339304	-8	-80	72	341352	-9	-86	77	339304	339304
															256	340328	-6	-87	81	339304	-9	-85	76	341352	-8	-85	77	339304	339304
					4	339337	339376	-59	-88	29	339337	-54	-88	34	32	340361	-69	-81	12	339337	-56	-65	9	341385	-64	-76	12	339337	339337
															64	340361	-57	-79	22	339337	-58	-77	19	341385	-60	-82	22	339337	339337
															128	340361	-56	-85	29	339337	-55	-82	27	341385	-56	-87	31	339337	339337
															256	340361	-54	-87	33	339337	-56	-86	30	341385	-56	-86	30	339337	339337
					5	339359	339376	-74	-88	14	683	28	44	16	32	1024	-6	-15	9	682	26	32	6	382085	16	5	11	0	380037
															64	1024	-2	-18	16	683	32	42	10	2048	-2	-18	16	0	0
															128	1024	-2	-19	17	683	26	41	15	2048	-1	-19	18	0	0
															256	1024	-1	-20	19	683	28	44	16	2048	-1	-19	18	0	0
7	413835	12	-2	14	1	249741	251181	57	-91	148	249741	52	-91	143	32	250765	27	-42	69	249741	4	-44	48	251789	-3	-35	32	249741	249741
															64	250765	31	-60	91	249741	29	-67	96	251789	18	-52	70	249741	249741
															128	250765	48	-91	139	249741	43	-80	123	251789	46	-85	131	249741	249741
															256	250765	48	-90	138	249741	45	-84	129	251789	46	-86	132	249741	249741
					2	251137	251181	-17	-91	74	251137	-15	-91	76	32	252161	-38	-67	29	251137	-39	-60	21	253185	-42	-65	23	251137	251137
															64	252161	-17	-71	54	251137	-29	-68	39	253185	-28	-78	50	251137	251137
															128	252161	-16	-89	73	251137	-18	-82	64	253185	-19	-88	69	251137	251137
															256	252161	-16	-90	74	251137	-19	-87	68	253185	-18	-88	70	251137	251137
					3	251152	251181	-41	-91	50	251152	-45	-91	46	32	252176	-58	-78	20	251152	-55	-70	15	253200	-58	-76	18	251152	251152
															64	252176	-48	-81	33	251152	-50	-80	30	253200	-49	-85	36	251152	251152
															128	252176	-47	-87	40	251152	-44	-84	40	253200	-46	-89	43	251152	251152
															256	252176	-46	-90	44	251152	-47	-89	42	253200	-47	-89	42	251152	251152
					4	251160	251181	-61	-91	30	251160	-64	-91	27	32	252184	-66	-78	12	251160	-66	-75	9	234572	18	7	11	251160	232524
															64	252184	-55	-78	23	251160	-63	-82	19	253208	-66	-84	18	251160	251160
															128	252184	-65	-90	25	251160	-61	-86	25	253208	-65	-91	26	251160	251160
															256	252184	-64	-90	26	251160	-64	-91	27	253208	-65	-91	26	251160	251160
					5	251173	251181	-82	-91	9	413827	12	-2	14	32	1024	-8	-14	6	43872	-19	-14	5	234572	18	7	11	0	232524
															64	1024	-4	-18	14	236132	15	6	9	2048	-2	-19	17	0	0
															128	1024	-1	-19	18	323764	10	-1	11	2048	-1	-20	19	0	0
															256	1024	-1	-19	18	315630	36	24	12	2048	-1	-19	18	0	0
8	4979	24	41	17	1	45992	79102	110	-85	195	45992	105	-85	190	32	47016	49	-30	79	45992	42	-22	64	48040	34	-11	45	45992	45992
															64	47016	57	-64	121	45992	78	-51	129	48040	66	-50	116	45992	45992
															128	47016	102	-86	188	45992	91	-72	163	48040	98	-76	174	45992	45992
															256	47016	103	-78	181	45992	97	-76	173	48040	96	-76	172	45992	45992
					2	79062	79102	13	-85	98	79062	16	-85	101	32	80086	-1	-41	40	79062	-19	-52	33	81110	-17	-45	28	79062	79062
															64	80086	2	-70	72	79062	3	-67	70	81110	-3	-63	60	79062	79062
															128	80086	16	-82	98	79062	10	-75	85	81110	11	-79	90	79062	79062
															256	80086	15	-82	97	79062	11	-80	91	81110	11	-80	91	79062	79062
					3	79079	79102	-39	-85	46	79079	-36	-85	49	32	80103	-41	-59	18	79079	-33	-48	15	81127	-52	-66	14	79079	79079
															64	80103	-23	-57	34	79079	-44	-69	25	81127	-46	-79	33	79079	79079
															128	80103	-39	-81	42	79079	-37	-77	40	81127	-38	-82	44	79079	79079
															256	80103	-36	-84	48	79079	-39	-82	43	81127	-39	-82	43	79079	79079
					4	79089	79102	-61	-85	24	79089	-55	-85	30	32	80113	-61	-72	11	79089	-62	-71	9	151740	-10	-21	11	79089	149692
															64	80113	-60	-79	19	79089	-57	-76	19	81137	-61	-82	21	79089	79089
															128	80113	-57	-83	26	79089	-54	-79	25	81137	-56	-84	28	79089	79089
															256	80113	-55	-84	29	79089	-57	-83	26	81137	-57	-83	26	79089	79089
					5	79099	79102	-80	-85	5	4979	24	41	17	32	6003	26	34	8	4979	28	36	8	228885	12	1	11	4979	226837
															64	6003	30	43	13	4979	26	38	12	7027	25	40	15	4979	4979
															128	6003	25	42	17	4979	23	39	16	7027	24	41	17	4979	4979
															256	6003	54	55	1	4979	24	41	17	7027	24	41	17	4979	4979
9	7127	4	22	18	1	99829	321015	76	-80	156	99829	72	-80	152	32	100853	24	-26	50	99829	21	-29	50	101877	19	-18	37	99829	99829
															64	100853	42	-48	90	99829	50	-52	102	101877	42	-48	90	99829	99829
															128	100853	73	-80	153	99829	62	-68	130	101877	66	-73	139	99829	99829
															256	100853	70	-80	150	99829	64	-72	136	101877	65	-73	138	99829	99829
					2	320916	321015	23	-80	103	320916	23	-80	103	32	321940	1	-46	47	320916	-8	-43	35	322964	-13	-41	28	320916	320916
															64	321940	7	-59	66	320916	8	-62	70	322964	4	-62	66	320916	320916
															128	321940	23	-78	101	320916	18	-72	90	322964	19	-76	95	320916	320916
															256	321940	19	-81	100	320916	19	-75	94	322964	18	-76	94	320916	320916
					3	320956	321015	-13	-80	67	320956	-14	-80	66	32	321980	-31	-56	25	320956	-34	-52	18	323004	-35	-56	21	320956	320956
															64	321980	-23	-67	44	320956	-26	-61	35	323004	-24	-71	47	320956	320956
															128	321980	-16	-80	64	320956	-18	-72	54	323004	-17	-76	59	320956	320956
															256	321980	-14	-78	64	320956	-18	-76	58	323004	-18	-76	58	320956	320956
					4	320979	321015	-46	-80	34	320979	-47	-80	33	32	322003	-42	-54	12	320979	-52	-62	10	323027	-54	-67	13	320979	320979
															64	322003	-49	-69	20	320979	-49	-67	18	323027	-51	-75	24	320979	320979
															128	322003	-50	-78	28	320979	-46	-74	28	323027	-49	-77	28	320979	320979
															256	322003	-47	-79	32	320979	-49	-78	29	323027	-49	-78	29	320979	320979
					5	321001	321015	-69	-80	11	7127	4	22	18	32	8150	8	16	8	7127	4	11	7	113224	-19	-30	11	7126	111176
															64	8151	3	17	14	7127	4	17	13	9175	5	20	15	7127	7127
															128	8151	4	21	17	7127	4	20	16	9175	4	22	18	7127	7127
															256	1024	1	-17	18	7127	4	22	18	9175	4	22	18	0	7127
10	72202	-3	12	15	1	6546	95399	72	-87	159	6546	70	-87	157	32	7570	23	-44	67	6546	18	-38	56	8594	13	-28	41	6546	6546
															64	7570	46	-65	111	6546	40	-59	99	8594	36	-51	87	6546	6546
															128	7570	70	-84	154	6546	60	-76	136	8594	65	-80	145	6546	6546
															256	7570	68	-86	154	6546	63	-80	143	8594	63	-79	142	6546	6546
					2	95300	95399	20	-87	107	95300	20	-87	107	32	96324	-15	-53	38	95300	-16	-49	33	97348	-23	-53	30	95300	95300
															64	96324	6	-67	73	95300	4	-67	71	97348	0	-70	70	95300	95300
															128	96324	19	-85	104	95300	13	-78	91	97348	16	-82	98	95300	95300
															256	96324	17	-85	102	95300	14	-81	95	97348	14	-82	96	95300	95300
					3	95350	95399	-28	-87	59	95350	-24	-87	63	32	96374	-47	-74	27	95350	-39	-61	22	97398	-43	-65	22	95350	95350
															64	96374	-31	-75	44	95350	-32	-75	43	97398	-34	-75	41	95350	95350
															128	96374	-24	-86	62	95350	-26	-80	54	97398	-26	-84	58	95350	95350
															256	96374	-26	-85	59	95350	-26	-85	59	97398	-26	-85	59	95350	95350
					4	95367	95399	-55	-87	32	95367	-50	-87	37	32	96391	-70	-81	11	95367	-58	-67	9	97415	-62	-75	13	95367	95367
															64	96391	-52	-78	26	95367	-56	-75	19	97415	-57	-81	24	95367	95367
															128	96391	-53	-85	32	95367	-51	-80	29	97415	-53	-85	32	95367	95367
															256	96391	-51	-87	36	95367	-52	-85	33	97415	-52	-85	33	95367	95367
					5	95385	95399	-78	-87	9	72202	-3	12	15	32	430150	-8	-8	0	2163	23	31	8	63081	20	31	11	429126	61033
															64	430150	-14	-13	1	2162	16	25	9	150173	11	-2	13	429126	148125
															128	430150	-18	-18	0	2163	24	36	12	4211	25	39	14	429126	2163
															256	430150	-18	-17	1	2163	25	39	14	4211	25	39	14	429126	2163

*S = time domain location in samples

*QL = amplitude quantization levels

*D = QL difference between samples

RED = incorrectly detected samples

GREY = sample detected accounting for zero offset

ERROR CALCULATIONS

ERRORS PER BITRATE

- **32KBPS**

Total Error = 53/150, 35.3333333333333%
Mean Error # = 10.6
Standard Deviation = 11.341957503006

- **64KBPS**

Total Error = 41/150, 27.33333333%
Mean Error # = 8.2
Standard Deviation = 11.214276615101

- **128KBPS**

Total Error = 35/150, 23.3333333333333%
Mean Error # = 7
Standard Deviation = 11.593101396952

- **256KBPS**

Total Error = 33/150, 22%
Mean Error # = 6.6
Standard Deviation = 11.757550765359

Splice 1
32 – 0/30, 0%
64 – 0/30, 0%
128 – 0/30, 0%
256 – 0/30, 0%
Splice 2
32 – 0/30, 0%
64 – 0/30, 0%
128 – 0/30, 0%
256 – 0/30, 0%
Splice 3
32 – 7/30, 23.3333333333333%
64 – 4/30, 13.3333333333333%
128 – 1/30, 3.33333333333333%
256 – 0/30, 0%
Splice 4
32 – 16/30, 53.3333333333333%
64 – 7/30, 23.3333333333333%
128 – 4/30, 13.3333333333333%
256 – 3/30, 10%
Splice 5
32 – 30/30, 100%
64 – 30/30, 100%
128 – 30/30, 100%
256 – 30/30, 100%

ERRORS PER COMPRESSION TYPE

BY BITRATE

- **AAC**

Total Error = 51/200, 25.5%
Mean Error # = 12.75
Standard Deviation = 2.046338193

- **MP3**

Total Error = 52/200, 26%
Mean Error # = 13
Standard Deviation = 2.449489743

- **WMA**

Total Error = 59/200, 29.5%
Mean Error # = 14.75
Standard Deviation = 3.34477204

AAC
32 - 16/50, 32%
64 - 13/50, 26%
128 - 11/50, 22%
256 - 11/50, 22%

MP3
32 - 17/50, 34%
64 - 13/50, 26%
128 - 11/50, 22%
256 - 11/50, 22%

WMA
32 - 20/50, 40%
64 - 15/50, 30%
128 - 13/50, 26%
256 - 11/50, 22%

BY SPLICE VALUE

- **AAC**

Total Error = 51/200, 25.5%
Mean Error # = 10.2
Standard Deviation = 15.184202316882

- **MP3**

Total Error = 52/200, 26%
Mean Error # = 10.4
Standard Deviation = 15.160474926598

- **WMA**

Total Error = 59/200, 29.5%
Mean Error # = 11.8
Standard Deviation = 14.891608375189

AAC
Splice 1 – 0/40, 0%
Splice 2 – 0/40, 0%
Splice 3 – 3/40, 7.5%
Splice 4 – 8/40, 20%
Splice 5 – 40/40, 100%

MP3
Splice 1 – 0/40, 0%
Splice 2 – 0/40, 0%
Splice 3 – 3/40, 7.5%
Splice 4 – 9/40, 22.5%
Splice 5 – 40/40, 100%

WMA
Splice 1 – 0/40, 0%
Splice 2 – 0/40, 0%
Splice 3 – 6/40, 15%
Splice 4 – 13/40, 32.5%
Splice 5 – 40/40, 100%

ERRORS PER SPLICE VALUE

- **SPLICE 1**

Mean Size Increase % = 1015.046348%
Mean Size Increase # = 295.4
Standard Deviation = 210.4087451

1-1 – 502/86, 583.7209302325581%
2-1 – 845/142, 595.0704225352113%
3-1 – 313/23, 1360.869565217391%
4-1 – 280/19, 1473.684210526316%
5-1 – 175/20, 875%
6-1 – 181/16, 1131.25%
7-1 – 148/14, 1057.142857142857%
8-1 – 195/17, 1147.058823529412%
9-1 – 156/18, 866.6666666666667%
10-1 – 159/15, 1060%

Total Error % = 0%
Mean Error # = 0
Standard Deviation = 0

1-1 – 0/13, 0%
2-1 – 0/13, 0%
3-1 – 0/13, 0%
4-1 – 0/13, 0%
5-1 – 0/13, 0%
6-1 – 0/13, 0%
7-1 – 0/13, 0%
8-1 – 0/13, 0%
9-1 – 0/13, 0%
10-1 – 0/13, 0%

- **SPLICE 2**

Mean Size Increase % = 666.750872%
Mean Size Increase # = 204.6
Standard Deviation = 162.7858716

1-2 – 377/86, 438.3720930232558%
2-2 – 620/142, 436.6197183098592%
3-2 – 232/23, 1008.695652173913%
4-2 – 188/19, 989.4736842105263%
5-2 – 112/20, 560%
6-2 – 135/16, 843.75%
7-2 – 74/14, 528.5714285714286%
8-2 – 98/17, 576.4705882352941%
9-2 – 103/18, 572.2222222222222%
10-2 – 107/15, 713.3333333333333%

Mean Error % = 0%
Mean Error # = 0
Standard Deviation = 0

1-2 – 0/13, 0%
2-2 – 0/13, 0%
3-2 – 0/13, 0%
4-2 – 0/13, 0%
5-2 – 0/13, 0%
6-2 – 0/13, 0%
7-2 – 0/13, 0%
8-2 – 0/13, 0%
9-2 – 0/13, 0%
10-2 – 0/13, 0%

- **SPLICE 3**

Mean Size Increase % = 366.8902241%
Mean Size Increase # = 110.5
Standard Deviation = 88.94858065
1-3 – 172/86, 200%

2-3 – 351/142, 247.1830985915493%
3-3 – 140/23, 608.695652173913%
4-3 – 75/19, 394.7368421052632%
5-3 – 65/20, 325%
6-3 – 80/16, 500%
7-3 – 50/14, 357.1428571428571%
8-3 – 46/17, 270.5882352941176%
9-3 – 67/18, 372.2222222222222%
10-3 – 59/15, 393.3333333333333%

Mean Error % = 9.230769231%
Mean Error # = 1.2
Standard Deviation = 2.271563338

1-3 – 4/13, 30.76923076923077%
2-3 – 7/13, 53.84615384615385%
3-3 – 0/13, 0%

4-3 – 1/13, 7.692307692307692%
5-3 – 0/13, 0%
6-3 – 0/13, 0%
7-3 – 0/13, 0%
8-3 – 0/13, 0%
9-3 – 0/13, 0%
10-3 – 0/13, 0%

- **SPLICE 4**

Mean Size Increase % = 174.422025%
Mean Size Increase # = 51.7
Standard Deviation = 40.86575584

1-4 – 77/86, 89.53488372093023%
2-4 – 165/142, 116.1971830985915%
3-4 – 60/23, 260.8695652173913%
4-4 – 33/19, 173.6842105263158%
5-4 – 33/20, 165%
6-4 – 29/16, 181.25%
7-4 – 30/14, 214.2857142857143%
8-4 – 24/17, 141.1764705882353%
9-4 – 34/18, 188.8888888888889%
10-4 – 32/15, 213.3333333333333%

Mean Error % = 23.076923080%
Mean Error # = 3
Standard Deviation = 3.660601044

1-4 – 12/13, 92.30769230769231%
2-4 – 7/13, 53.84615384615385%
3-4 – 2/13, 15.38461538461538%
4-4 – 4/13, 30.76923076923077%
5-4 – 3/13, 23.07692307692308%
6-4 – 0/13, 0%
7-4 – 1/13, 7.692307692307692%
8-4 – 1/13, 7.692307692307692%
9-4 – 0/13, 0%
10-4 – 0/13, 0%

- **SPLICE 5**

Mean Size Increase % = 61.9435%
Mean Size Increase # = 22.2
Standard Deviation = 26.28611801

1-5 – 32/86, 37.2093023255814%
2-5 – 98/142, 69.01408450704225%
3-5 – 20/23, 86.95652173913043%
4-5 – 15/19, 78.94736842105263%
5-5 – 9/20, 45%
6-5 – 14/16, 87.5%
7-5 – 9/14, 64.28571428571429%
8-5 – 5/17, 29.41176470588235%
9-5 – 11/18, 61.11111111111111%
10-5 – 9/15, 60%

Mean Error % = 100%
Mean Error # = 13
Standard Deviation = 0

1-5 – 13/13, 100%
2-5 – 13/13, 100%
3-5 – 13/13, 100%
4-5 – 13/13, 100%
5-5 – 13/13, 100%
6-5 – 13/13, 100%
7-5 – 13/13, 100%
8-5 – 13/13, 100%
9-5 – 13/13, 100%
10-5 – 13/13, 100%