TAPE ANALYSIS AND AUTHENTICATION USING MULTI-TRACK RECORDERS

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Techniques and advantages of multi-track (> quarter track) playback heads for forensic analysis of standard monophonic and stereophonic cassette and micro-cassette tape recordings is discussed. The time-domain waveform for recorded signatures can be analyzed in terms of relative timing offset for determining azimuth of the record head used in making a specimen tape. Additionally, excursion of the erase signature into the guard band region is a reliable indicator of an original versus a copied erase signature. Comparative advantages over magnetic development techniques are discussed.

1 INTRODUCTION; AUTHENTICATION IN GENERAL

In many cases, an audio forensic expert is called upon to examine taped evidence to provide an opinion on whether or not a tape has been "edited" or "doctored" in any way. Specifically, this translates into an analysis of the temporal sequence of events found on the tape that correspond to record start, pause, and stop operations of one or more tape recording devices. This typically includes the analysis of "record event signatures" corresponding to the interaction of the tape surface with the electrical activation and deactivation of AC-bias record and erase heads, and/or contact with a permanent magnet erase head.

Record event signatures, if they exist, may or may not be revealed via a number of techniques that are applied in the audio forensic laboratory. This includes aural analysis ("critical listening"); visual analysis of the time-domain waveform ("waveform analysis"); and via visual analysis of the bitter pattern of the magnetized surface of the tape ("magnetic development"). The bitter pattern, a visual representation of the magnetized portions of the tape rendered visible through a lowpower microscope, results from the application of micron-sized iron particles in a liquid suspension to the tape known as "ferrofluid". A camera or video recorder can be used to document the event. Several key papers in the literature address the use of these techniques [1,2,3]. Figure 1 illustrates a comparison of the same record event seen via Magnetic development (top) and time-domain waveform (bottom).



Figure 1: Magnetic development (top) and timedomain waveform (bottom) of the same record event (record stop signature). The magnetic development photo has been reversed to match the sequence of events as would be transmitted to the computer by the playback head.

In addition to examining record event signatures to determine continuity or editing, audio forensic experts are also sometimes asked to confirm if an evidence tape is an original recording, or a copy. Evidence of an original versus a copied tape usually results from similar record event signature analysis, whenever possible. While it is possible to determine that a record stop event is a copy via the analysis techniques just described, an audio forensic expert can never determine with absolute certainty if a recording is truly "original"; one can only state that the recording is consistent with an original



Figure 2. Tape head configuration for $\frac{1}{4}$ track stereo tape (indicated as C, boxed). The two bottommost tracks correspond to left and right channels of the "A" side of a tape; the two uppermost tracks correspond to the left and right channels of the "B" side of the tape. The middle area between the A and B side head pairs is referred to as the center 'guard band'.

recording. As an example, an original recording can be recorded to a computer, digitally edited, and then played back to a cassette recorder containing a tape with "leader" at the start and end. The leader cannot be recorded upon since it has no metallic surface that can be magnetized. The action of the tape recorder corresponding to the record start and record stop events cannot be observed via either waveform or magnetic development analysis.

Another area of authentication not considered here is matching a tape to a specific tape recorder used to make the evidence recording. It is on occasion useful for an attorney to have an audio forensic expert impugn the reliability of a witness's testimony in cases where a specific tape recorder is claimed to have been used to make a specific evidence tape. Intra-machine variability viewed with inter-machine variability makes it far easier for an expert to eliminate a specific machine rather to identify it. (There is a corresponding observation regarding voice identification; see paper by F. Poza and D. Begault, *Voice identification and elimination using aural-spectrographic protocols*, this conference).

Finally, the forensic audio expert and legal practitioners must bear in mind the difference between what has been termed "Technical Authentication" versus "Legal Authentication". While related, the audio forensic expert is not required nor are they responsible to legally authenticate evidence in the legal sense [1]. Technical authentication is within the expertise of the audio forensic expert.

2 WAVEFORM ANALYSIS

Waveform analysis begins with the archival playback of the evidence tape into a computer for digital storage, using a high quality tape recorder for playback having the same type of head configuration used in the original recording. For example, a ¹/₄ track stereo cassette tape, which is one of the most popular formats, is played back for digital storage and analysis on a computer using a ¹/₄ track stereo cassette tape machine (see Figure 2 for various formats of tape). Procedures such as those outlined in Audio Engineering Standard 43-2000 "Criteria for the authentication of analog audio tape recordings" can be followed.

A computer with calibrated, high-quality analog-digital converters and appropriate software essentially act as a high-quality tape recorder. Once archived, the use of an audio recording waveform editor greatly simplifies navigation throughout the 'unaltered' (direct, one-one) copy of the audio contained on the entire evidence tape, and critical listening can be combined with visual observation to mark significant events for further inspection. Similar or more detailed visual analyses corresponding to a photograph of an oscillograph trace can be accomplished by "zooming" in on the display, including with "scientific analysis" software (such as Mathworks' MATLAB).

Spectrographic analysis, which analyzes the strength of various frequency components, can also be used "on the fly". Record event signatures, particularly pause signatures, are also sometimes detectable in this manner. (A spectrum is analogous to the bands of light seen when a light source is placed in front of a prism. Spectrographic and other frequency analysis techniques, such as Fourier analysis, are beyond the scope of this discussion).

Of the various types of record event signatures, record stops are most visible using waveform analysis due to the characteristic large peak of the record head electrical discharge, followed by the low-frequency erase head discharge (see Figure 1). The erase head signature is also commonly audible as low-frequency "thump". Record start signatures are sometimes more difficult to see, as one observes an energizing of the waveform as an amplitude increase, often convolved with the waveform of the input [2]. Pause signatures are sometimes, but not always easy to observe using just waveform analysis. Overall, waveform analysis allows a relatively simple means for examining discontinuities across long recordings, which can be observable from either the presence of signatures, just discussed, and/or from changes in background noise.

3 MAGNETIC DEVELOPMENT

For short-duration events, magnetic development has historically been considered to be superior to waveform development for forensic analysis. For example, one can immediately observe the track width and configuration from a photograph of the bitter pattern, as well as determine recorded from unrecorded tape. Comparing Figure 1 to Figure 2 shows that the examined tape in Figure 1 is unrecorded on side B and that the track configuration of side A corresponds to a ¹/₄ track tape configuration.

Magnetic development also clearly indicates in some instances an original versus a copied record head signature. Figure 3, left shows the non-flat surface of a record head signature from an original recording, caused by vertical motion (droop) of the tape resulting from the mechanical action of the recorder. Figure 3, right shows the same record head signature on a copied tape. There is no droop on the copied tape; however, this signature could have also been found on an original tape, caused by a recorder that did not move the tape vertically. Examination of the erase head mark would provide additional clarification.



Figure 3. Magnetic development of record head signatures. Left: from an original recording. Right: from a copy of the same tape.

Less ambiguously, magnetic development can also reveal over-recordings (two overlapping bitter patterns or via two record head edge traces). The difference in height of the two traces in Figure 4 indicates two different recordings, one caused by an over-recording. Also note the fact that the vertical height of the erase head signature is greater than the vertical height of the record head trace. This is an illustration of the means by which an original erase head signature is visible via magnetic development. A dubbed version of this erase head signature would be the same height as the record head. This is due to the fact that erase heads are generally manufactured to exceed the vertical extent of the record head, to insure complete erasure of recordings within a range of record head alignments.



Figure 4. Magnetic development of a record-over signature.

4 DISADVANTAGES & CAUTIONS RE MAGNETIC DEVELOPMENT

Magnetic development has advantages over waveform analysis or other methods for detecting and observing the types of signatures just discussed. However, there are also several disadvantages to the method that must be considered. First, the process is time-consuming and consequently expensive for clients. This is because only a small portion of the tape, maybe several inches, can be removed safely from the tape at one time.

Consider that at a speed of 1 7/8 inches per second, twelve inches of tape corresponds to about six seconds. This is fine for investigating a single event, such as a record stop where the distance between the record and erase head is usually about one inch. But an examiner cannot practically magnetically develop an entire tape; a 30minute tape would require development of 3375 inches of tape and investigation of about half as many photographs. Hence, magnetic development is typically performed to confirm the results of critical listening and waveform analysis for specific events.

Another disadvantage of magnetic development relative to waveform analysis is that the signals must be relatively high amplitude in order to be visible. "...certain record and erase head events from some tape recorders may be too weak to be exhibited" [1]. In fact, record events such as record stops that are visible with magnetic development are nearly always audible. By contrast, waveform analysis allows investigation of signals that exceed the (usually very low) noise floor of the computer recording. (In a future study, we plan to compare the minimum detectable signal level observable using magnetic development).



Figure 5. Signal loss due to magnetic development of tape having a pink-noise spectrum. Left: result of subtracting the "before" from the "after: spectra for six tapes. Right: same data with 2^{nd} order polynomial curve fit.

However, the principal disadvantage of magnetic development is potential damage to the evidence tape itself. Magnetic tape used in cassettes consists of an extremely thin base film $(6 - 12 \ \mu\text{m})$ with an oxide coating of about 5 μ m, and is susceptible to stretching and folding [4]. Its preservation is by design dependent on the protective cassette housing and reels, which only exposes a small portion of the tape at one time while keeping a flat, tight wind on each tape hub.

Figure 5 shows results of tests from the Audio Forensic Center laboratory using specimen cassette tapes to test for signal loss from magnetic development conducted by two experienced examiners. Six virgin cassette tapes (Maxell XLII-S 90) had a recording of pink noise applied using a Sony TCD-5 professional cassette recorder. The "before" spectrum was analyzed for each tape individually, using a Hewlett-Packard HP5670A real-time FFT analyzer (100 averages of a four-second looped segment, Hann window). Then, a small amount of ferrofluid ("Kyread F concentrate" manufactured by Kyros Corporation, in a 1,1,2 Tricholotrifluoro-ethane ("Freon") base) was applied to each tape and allowed to dry. The residue was wiped off using a soft disposable cloth ("Kimwipe") and then the tape was rewound and re-played for FFT analysis using the same cassette playback device to obtain an "after" spectrum in the same manner as the "before" spectrum. The tape playback head was cleaned and dried before each playback to control for residue from previous tapes.

Additional tests conducted in our laboratory using individual sine wave frequencies also indicated signal loss consistent with the results of Figure 5. Table I shows the mean value and raw data for three tapes prepared with three sine wave tones (1.7, 4 and 10 kHz) for the "before" and "after" spectra. Similar or greater losses were observed using a ferrofluid manufactured by FerroTec (type EMG 408). Additional 'wiping' of tapes did not offset the observed losses.

Taken together, these data indicate that magnetic development of tapes can cause damage to an evidence tape in terms of signal loss, particularly in higher frequencies. The amount of loss may be due to the amount of iron particles not removed during a specific test. This loss may impact alternative methods of examining a tape after magnetic development is performed, including waveform analysis, spectral analysis and critical listening, and may also impact the enhancement of speech recordings. Furthermore, the signal loss is probably permanent, due to the interaction of the metal particles of the ferrofluid with the magnetized oxide surface. Finally, there is the possibility of folding and creasing of the tape due to its removal from its protective shell, which can permanently damage the high frequency content of a tape.

	1.7 kHz	4 kHz	10 kHz
1	1	1	3
2	2	3	4
3	3	3	2
MEAN	2.0	2.3	3.0

Table I. Signal loss (dB) from magnetic development of three tapes recorded with 1.7 kHz, 4 kHz and 10 kHz tones (Sony TCD5), along with mean values.

5 MULTI-TRACK HEAD WAVEFORM ANALYIS

It would be advantageous to utilize waveform analysis as a substitute for magnetic development in order to prevent damage to an evidence tape. The technique of using multi-track playback heads for forensic analysis of standard monophonic and stereophonic cassette and micro-cassette tape recordings is a useful alternative for determining whether record stop signatures were made on the evidence tape ('original record stop signature') or on a later generation of the tape ('copied record stop signature'). This is a form of technical authentication that can be useful in making probative statements regarding the originality of the evidence.

Audio Forensic Center has evaluated multi-track cassette units from Tascam Corporation 688 (8 track standard Cassette) and JBR Technology (4 track microcassette, and 2 track-9 track magneto-resistive head for standard Cassette) for their application to determining copied from original tapes, and for other functions. Preliminarily, it is possible to report that the multi-track units reveal pertinent information regarding erase head marks and track configuration that would otherwise only be observable via the bitter pattern produced by magnetic development.

The 8-track head configuration labeled "B" in Figure 2 is that used in the Tascam multitrack recorder 688. Figure 6 shows the eight tracks via magnetic development of the bitter pattern from recording of a 315 Hz sine wave. The middle two tracks (numbering sequentially, tracks 4 and 5) are indicated with arrows in Figure 6. The location of these tracks lies within the guard band area of $\frac{1}{2}$ track and $\frac{1}{4}$ track recordings (see configurations "C" and "D" in Figure 2), and erase head signatures typically only occur in these track regions with original tapes. However, due to head misalignment on original recordings, the middle tracks are sometimes not completely centered over the guard band.



Figure 6. Magnetic development showing layout of tracks (dark stripes) on Tascam 688 8-track cassette playback head. Arrows indicate tracks that correspond to the center guard band of a standard $\frac{1}{4}$ track and $\frac{1}{2}$ track recording.



Figure 7. Layout of head on JBR Technology's 2 track-9 track magneto-resistive head cassette playback machine (approximate-not to exact scale). Left (open rectangles): location of stereo $\frac{1}{4}$ track record-playback head (width 600 µm); center (solid rectangles): location of magnetoresistive head (width 70 µm); right: approximate erase head location.

Figure 6 shows how the arrangement of the track heads for the 2 track-9 track magneto-resistive head cassette playback machine corresponds to the standard head layout of a ¹/₄-track stereo cassette. As shown in Figure 1 and detailed in Figure 7, a tape recorder erase head is wider than the width corresponding to the audio tracks.

By using a multitrack magnetoresistive head with narrow gap width (70 μ m) there can be a more precise playback head track corresponding to the guard band region between the "A" and "B" side of the tape. Waveform analysis of the output of track 1 of this head will show detailed time-domain information from the erase head, if the signature was made on the original tape. The relative attenuation of audio in track 5 is an indicator of whether the analyzed tape wave ¹/₄ track stereo or ¹/₂ track monaural.

Consider the simple example of a tape where the recording is stopped perhaps one minute into the recording. On the original tape, a record stop signature will be visible via magnetic development with the erase head extending beyond the top of the audio track and into the "guard band" region between sides. On a copy the erase head mark would not be visible on track 1 (and sometimes, track 2).



Figure 8. Time domain view of erase head signatures as reproduced by the magnetoresistive head for $\frac{1}{2}$ track original (left side) and $\frac{1}{4}$ track copy (right side). Top: track 1; Bottom: track 2.

Figure 8 shows a comparison between an original tape (1/2-track hand-held Radio Shack recorder) and a dub made of the same tape between two $\frac{1}{4}$ track recorders. Figure 9 shows spectrograms of the same data from 0-500 Hz. The relatively higher frequencies seen in the erase head for Track 1 on the original tape are missing from Track 2.

6 ANALYSIS OF AZIMUTH ERROR

Azimuth refers to the position and angle of the record head or playback head in relation to an audiotape. Azimuth error results if a discrepancy exists between the azimuth of the record head and the playback head. Recorded audio data regarding the alignment of the azimuth of a record head may be used as an identifier to a particular recorder.

A reduced level of signal and signal degradation can occur if a misalignment of the record head causes an azimuth error during playback. Audio enhancement may require a playback head be aligned to the azimuth of a record head in order to improve signal quality from an evidence tape.



Figure 9. Spectogram of erase head signature, 0-500 Hz. Top: tracks 1,2 for original tape. Bottom: tracks 1,2 for dub.

The azimuth error resulting from an improperly aligned record head of a magnetic tape recorder can be quantified by analyzing multi-channel playback in the time domain. The time of arrival of the peak excursion of a record signal can be easily compared across a multitrack time domain display. Azimuth errors will be exhibited as successively increasing delta time delay values over adjacent heads of a multitrack playback recording. The delta time delay can then be used to determine the degree offset, top-to-bottom, of the azimuth. A simplified value for degree of azimuth error is represented as:

$$\theta = \tan^{-1} \frac{(\Delta t * s_{\text{playback}})}{(\Delta h)}$$

Where:

 $\begin{array}{l} \theta = Degree \ of \ azimuth \ error \\ \Delta t = Time \ delay \ between \ heads \ in \ seconds \\ s_{playback} = Speed \ of \ tape \ playback \ in \ cm/s \\ \Delta h = \ distance \ between \ heads \ in \ cm \end{array}$

This equation assumes the multitrack head used for forensic analysis has no azimuth error. Any error in the azimuth of the multitrack head would exaggerate the negative or positive delta time delay values over adjacent poles.

The precision of the multitrack head in determining angle of azimuth of an evidence recording is dictated by the sampling frequency of the digital copy of the recording (resolution of Δt) and the speed of the tape during playback (S_{playback}). The 9 track magnetoresistive head yields a precision of 0.04 degrees at a sampling rate of 44.1 khz and a tape speed of at 4.76 cm/s. Higher sampling rates are easily obtained using high-quality 'off-the-shelf' analog-digital converters.

7 CONCLUSION

While not a replacement for magnetic development in some circumstances, the advantages of multi-track waveform capture for forensic analysis of standard monophonic and stereophonic analog tape are numerous. Multi-track waveform analysis provides far more insight into the detail of an evidence tape than waveform analysis of one or two tracks that correspond to the original recorded track width. The tape may be examined for many important features that previously could only be examined using magnetic development.

Two features of multi-track waveform analysis were reviewed. First, the excursion of the erase signature into the guard band region is a reliable indicator of an original versus a copied erase signature, particularly when using 9 narrow tracks extending over half the vertical height of the tape. Second, the time-domain waveform for recorded signatures can be analyzed in terms of relative timing offset for determining the azimuth of the record head of a specific tape recorder used in making an evidence tape.

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