MAGNETO-RESISTIVE FIELD MAPPING OF ANALOG AUDIO TAPES FOR FORENSICS IMAGING*

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Magneto-resistive imaging of cassette tapes for forensic analysis applications is presented. Sample tapes were recorded on various tape recorders with events typically encountered in investigations. A comparison of the images with those obtained using ferrofluid is presented, along with comparisons of multiple instances of the same event with the various recorders

Keywords: Forensics, magnetic tape, magnetic imaging, magnetic field sensor, magneto-resistor, sensor array.

Introduction

Forensic audio analysis has been rapidly changing with the advent of the digital age. With analog magnetic tapes, such as cassettes and micro-cassettes, still being submitted as evidence, the challenge to the forensic community is to retain competence in analyzing these types of older media. In particular, it would be ideal to apply new digital methods to this analysis to reduce the effort and get more information. The traditional method of ferrofluid development and analysis is relatively mature and is probably most noteworthy as documented by the White House Tape Advisory Panel Report in 1974 [1]. Digital systems for capturing and analyzing the resulting Bitter patterns have been developed [2]; however, this technique is still limited by the drawback of requiring the examiner to extract the tape and develop short segments by hand. In addition, the dynamic range of ferrofluid is low and it is not possible to reconstruct the audio signal from a Bitter pattern. This is due to the fact that the strength of the magnetic field is not linearly related to the Bitter pattern and the polarity information of the signal is lost.

Recent work [3] showed that it is possible to use a scanned, second-harmonic magneto-resistive sensor to acquire images from tapes. These images have high dynamic range and measure the polarity of the signal. Subsequently, based on new advances in magneto-resistive technology [4], a high-speed imaging device, the magneto-resistive field mapping (MRFM) system, was developed that allowed the user to capture a magnetic image of the tape in real-time, i.e., as it was being played [5]. With this capability it is possible to scan an entire tape and archive the images for later analysis. To illustrate this, in Figure 1 we show a comparison between the MRFM and ferrofluid images. In the top panel one second's data from a cassette tape with a stop event is shown from the MRFM, and a zoomed in picture of the erase-head stop event is on the bottom right. A corresponding ferrofluid image of a similar erase head stop event from the same recorder is displayed on the bottom left. The MRFM display presents the magnetic data on the computer screen in a left to right format. Since the digital data are acquired in real time, various methods for displaying the data were examined for clarity and best functionality. For example, this method of display correlates well with the signal's waveform display, as will be described later.

Traditionally, ferrofluid images are displayed in the sequence as taken directly from the tape, which in the case of cassette tape record events causes the ferrofluid image to appear reversed from that of the MRFM image. This new method of display is more user-friendly and evident for judges and juries when they are confronted with this type of forensic data for the first time. From these images it can be seen that the erase-head edge mark leaves a much stronger signature down the length of the tape in the MRFM images, and the background noise is also much lower than in the ferrofluid image.

One of the key system design features of the MRFM is a linear array of 256 magneto-resistive sensors that allow the full width of the cassette tape to be scanned at high speed during normal playback. The magnetic field data (strength and polarity) are captured in real-time and are available to review aurally and visually from a given selection of the 256 sensors.

Therefore, the examiner can review and listen to the audio content directly from the images, and it is not necessary to play the tape again. Finally, with the calibration of the sensors it is possible to quantitatively analyze the events. In this paper we present some results of a study using the MRFM to acquire images of multiple instances of two different types of events recorded with a number of different makes and models of cassette recorders.

Test Protocol

The test artifacts consisted of four cassette tapes, all with the same events recorded on them. Separate tapes with the same events were recorded separately to be used for comparison to ferrofluid images. The events were recorded in two sessions:

- Session 1. Three similar stop/starts for each of six different recorders (18 events on each tape). In these events, the examiner stopped and started the recording while speaking into the microphone.
- Session 2. Three similar over-recording-start and over-recording-stops for each of the six recorders (18 events on each tape). In these events, the examiner first recorded himself counting, then went back and recorded over the counting for a few seconds.

The six different recorders used in the study represent typical types encountered in the course of forensics work [6]. The specific types included:

- Recorder a. Sony, Model TCM 260:
- Recorder b. Marantz, Model PMD221:
- Recorder c. Lanier.AL/CII
- Recorder d. Sony TCS-580,
- Recorder e. Marantz Model PMD430,
- Recorder f. Sony TCM-280.

The events were kept track of by tape number, event number, and recorder letter.

The tapes were then mounted into the MRFM system and played, allowing the examiner to listen to the tape while the magnetic field map image scrolls by on the screen. The system was configured to store an image from the previous 10 seconds of tape whenever the "grab" button was pressed. This allowed very rapid acquisition of images of the various events. When a suspected event was heard and seen on the screen, the examiner would "grab" that frame. Because both audio and visual cues were available, all of the test events were easily acquired upon initial playback. The images were stored in a lossless binary file, and could be analyzed and printed out by loading them back into the program.

Image Analysis

When analyzing the images, there were several steps used to zoom into a specific event. Because the tapes are only 4 mm wide, and 10 seconds of audio represents nearly 500 mm of tape, the first step is to display an image of the data in an expanded aspect ratio, i.e., with the y-scale expanded to show the full width of the tape. This is illustrated in Figure 2(a), where the first stop/start event from Recorder (f) is shown. From the image, the entire waveform, Figure 2(b), can be captured and played back by the computer by building a .wav file with the data. By use of the audio and visual cues, the event that appears from 191-241 mm can be isolated. The examiner can then zoom in on this area and plot it with a 1:1 aspect ratio, as shown in Figure 3(a).

With the combined image and audio from the MRFM, it is possible to do a quantitative evaluation of the events seen on the tape. This is because the MRFM gives the strength and polarity of the magnetic field from the tape. For example, it can be seen from Figure 3(c) that the magnetic field from the write head stop event (between 197 and 198 mm) reaches a peak of $H \approx 5$ kA/m, compared to the audio signals that stay below about ~2.5 kA/m, from Figure 2(b).

Note here that the units for field are measured in the SI system, where the H field is the fundamental quantity of measurement [7,8]. These numbers are derived from the calibration of the magnetic sensor array by moving it close to a coil, as described in Ref. 5. In brief, a known current ramp is applied to the coil, and the response function of each sensor is measured. From the coil dimensions, the applied field strength can be calibrated. To convert to the magnetic induction field, in tesla (T), the conversion factor of $B=\mu_0 H$ should be used, where $\mu_0=4\pi\times10^{-7}$ T/(A/m) is the magnetic constant. To convert to units in the cgs system, with 1 gauss corresponding to 10^{-4} T, the peak field of 5 kA/m corresponds to a flux density of more than 60 gauss.

In order to illustrate the reproducibility of the MRFM images, in each session we recorded multiple instances of the same type of events with each recorder, as described above. Figure 4 compares two stop/start events recorded with the same instrument. The erase head edge is clearly visible along the length of the tape; and left very similar marks each time. Differences between the images can be ascribed largely to tape quality. For example, in Figure 4(a) there is a large magnetic feature at 287 mm from the start of the image, while Figure 4(b) shows a smaller feature at about 252 mm.

The fact that the features are magnetic in origin is proved by the observation that they are dark on one side and bright on the other, indicating the existence of positive and negative magnetic poles. These features would appear in any imaging technique, and the advantage of the MRFM is that they can be mapped out with high resolution and positively identified as imperfections in the tape.

Discussion and Conclusion

A key question that is asked in a forensic exam is "can we link a certain recorder to a given recording?" The MRFM technique provides significantly improved resolution of the magnetic tapes to help answer that question. We show this in Figure 5(a) – (f). These images of similar events recorded in Sessions 1 with different recorders clearly show systematic details and features heretofore not available using the Bitter Pattern technique. Similarly, the images from the various events in Sessions 2 shows distinct, reproducible differences both qualitatively and quantitatively.

We found that it is possible, in principle, to make a complete magnetic map of an analog cassette tape with the MRFM. From this map it is possible to rebuild the audio signal and find events on the tape. This is a powerful technique because it allows examiners to make a virtual copy of the tape, which they can later go back and review without disturbing the evidence again. The magnetic maps allow quantitative analysis of the magnetic field strength and polarity, and show significant differences between makes and models of recording instruments. The technique is in the process to be validated for use on evidence. Additional tests will be conducted to rigorously understand the data that are available from these images.

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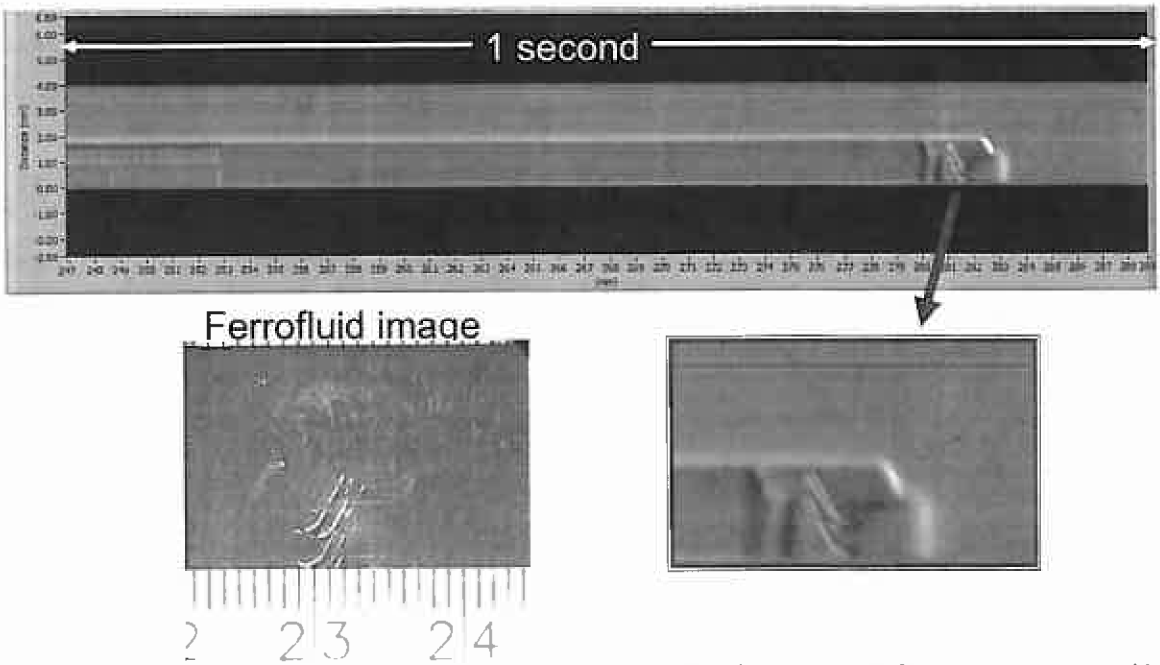

Figure 1 Example of an image captured by the Magnetoresistive Field Mapping system (MRFM) on a cassette tape with an erase head stop and write head stop mark. The erase head stop mark is compared to the ferrofluid Bitter pattern from the same piece of tape, where the scale is in millimeter. The MRFM image is flipped relative to ferrofluid because it reads the data in as the tape passes over the head, as described in the text.

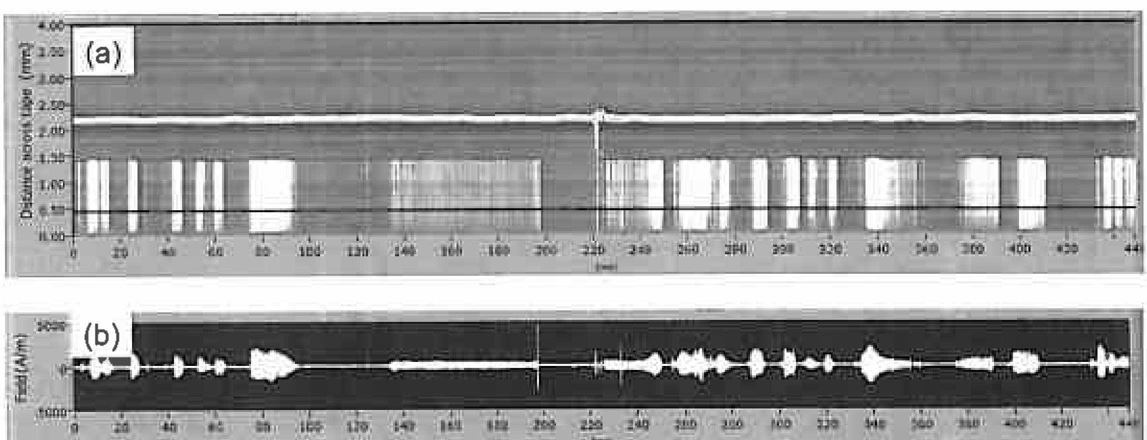

Figure 2 Identification of events directly from images. Panel (a) shows the expanded aspect ratio image of 10 seconds of data. Panel (b) shows the line scan of the magnetic field of the audio data along the solid line at 0.5 mm. These data are extracted directly from the image.

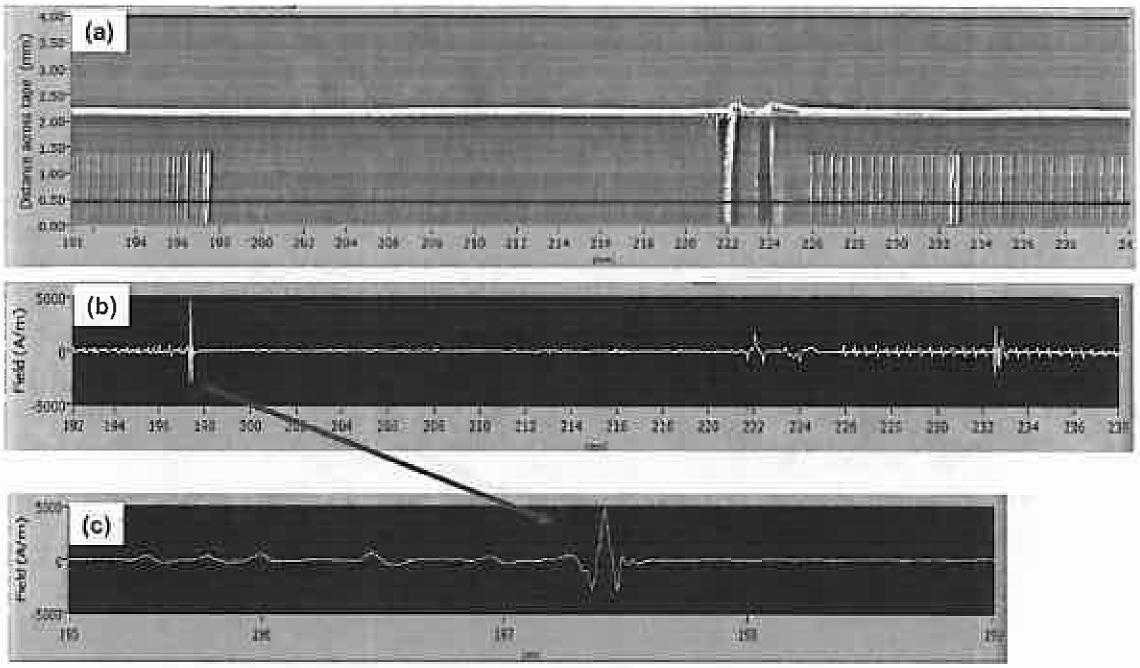

Figure 3 (a) 1:1 aspect ratio image of write-head stop event, 191 to 241 mm, from Figure 2; (b) line scan of data at 0.5 mm across tape (black line); and (c) zoomed in line scan from 195 to 199 mm.

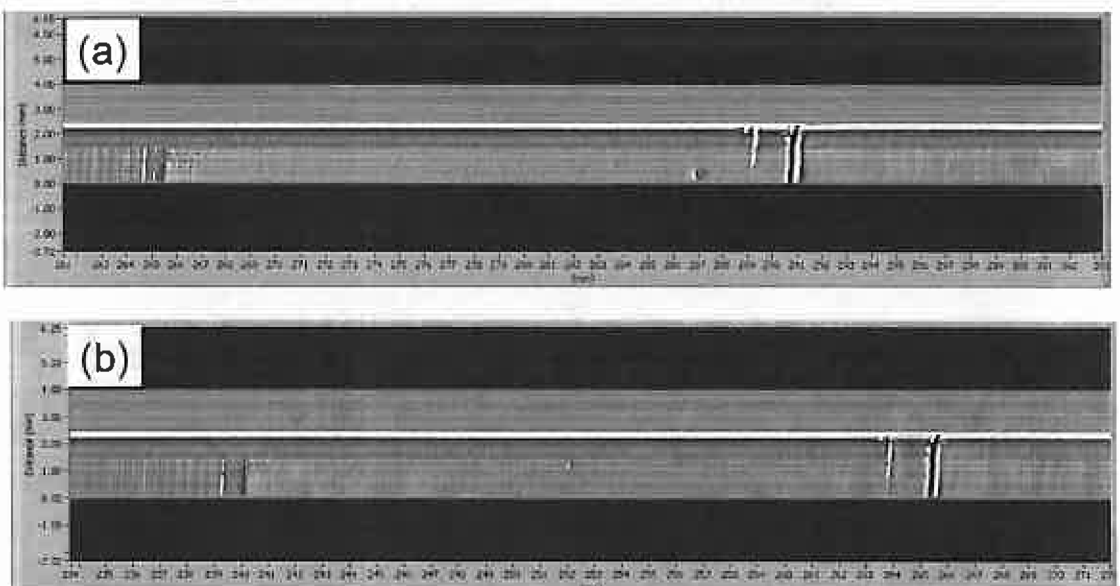

Figure 4 Two different instances on the same cassette tape of the same type of event (stop/start) and same recorder (Sony TCM 260).

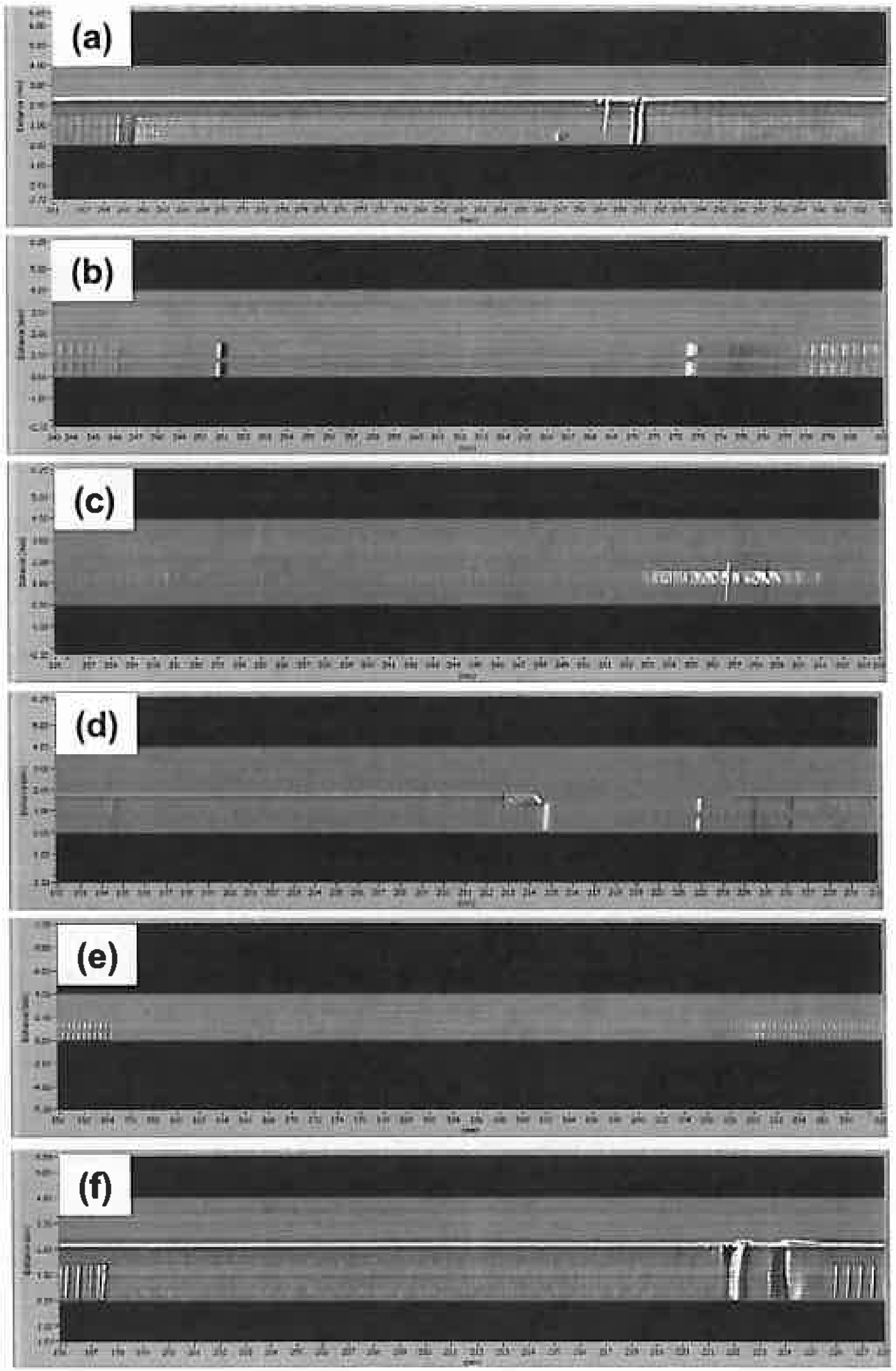

Figure 5 Images of stop/start marks made with different recording instruments. The recorders listed in the text correspond to the panel letters.

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