Spin Stand Microscopy of Hard Disk Data

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I shall be posting a series detailing the additional data not included in the paper [1] on recovering overwritten data in the following weeks.

My thanks to Dave Kleiman (one of the original papers co-author's with myself) for reviewing and adding some details to this post series.

Due to the limitations of peer reviewed papers, much of the detail of a process is commonly lost. This series of posts will endeavor to fill out the areas that are not covered in the paper in any detail and also add some further level of knowledge.

The recovery of data from damaged hard drives has come a long way over the years. Various techniques have been developed using both optical and electron microscopes and leading to the use of Magnetic force microscopy (MFM). MFM is a category of Scanning Probe Microscopy (SPM) and perhaps is the most widely used of these techniques. Of the techniques that can be commonly found, the primary ones are:

- The Bitter technique where the platter is coated with a thin film of ferro-fluid. This fluid contains ferro-particles which associated most strongly with the field vectors on the drive providing a magnetization pattern. This is known as a "Bitter patterns" and maps to the magnetic field vectors. Depending on the track density, either a high powered optical microscope or a scanning electron microscope (SEM) is used to observe the platters. This technique has become far less effective in recent times due to the increasing drive density. It can be used in the imaging of floppy drives. The technique is invasive and will result in the destruction of the drive platter.

- Lorentz microscopy uses an electron beam that is fired at the drive platter. Magnetic fields produce an effect known as the Lorentz force. This force deflects the electron beam. These deflections can be measured using a Scanning Electron Microscope (SEM). The SEM will then return the deflection pattern which can be used to "map" the encoded drive image. More recently, Transmission Electron Microscopes (TEM) have been used for this process. This is a slow process that is economically infeasible for use on most modern hard drives.

- Magnetic Force Microscopy is a variety of imaging techniques known as Scanning Probe Microscopy (SPM). This techniques uses an enormously fine (and expensive to replace) point that is mounted on a flexible cantilever. This tip "raster-scans" the drive platter following the magnetic force vectors. As the reader is coated with a ferromagnetic material, the field interactions attract or repel the tip. These movements are measured through the cantilever allowing an accurate map of the magnetization-induced field to be produced. Magnetic Force scanning Tunnelling Microscopy (MFSTM) is one form of MFM. This method uses the tunnelling currents that are created through the movement of the probe to produce a two-dimensional spatial map of the magnetic field coordinates. This map is used to decode the "bits" on the drive.

Electrostatic Force Microscope (EFM) works in an equivalent manner as the MFM. However, the EFM uses electrically charged probes and samples with a electrostatic structure, like ferroelectrics. Probe and sample form some kind of capacitor. What is really nice is that the EFM tip can write charge structures into the sample. The EFM cantilevers have to be conducting. It is not so easy to make them yourself but the EFM cantilevers can be bought from specialist companies just like the AFM probes.

MFM has many advantages over the other aforementioned techniques in the recovery of hard drive data. As referenced in my SANS post, Overwriting Hard Drive Data, it is not useful in recovering overwritten data on a drive. There are a number of problems with MFM methods in forensics and data recovery. The MFM used in the experiments conducted to determine that a single overwrite of data is sufficient had a 0.1 by 0.1 mm scanning range. This can scan several tracks – but you need to know the approximate location of the data being imaged before you begin.

Imaging a small known section of a drive using this technique is feasible with the imaging of 265 points being the average (mean) number of image points mapped in order to uncover the encoded pattern of writes and overwrites used in the determination of probabilities attached to recovering a single overwritten byte (there is also some variation based on the encoding itself here). However, with approximately 780,000 (or more) points needed to completely image a modern hard drive, the use of a MFM technique is not practical (nor economical). Worse, it is impractical to create a set of multiple two-dimensional images of the same target area of the drive such that you can lower the noise rate of the acquisition. In theory it is possible using spectral techniques, but this is computationally infeasible.

When considering the fact that several hundred thousand image points need to be mapped in scanning a hard drive, also consider the increasingly fine resolution of modern hard disk drives. An older drive has the requirements for a lower resolution due to a smaller bit density. As drive density increases, so does the resolution of the image need to increase. The increase in resolution corresponds to an increase in the time needed to create the image. Each point on the older drives (circa 1996) used in the previously mentioned experiment [1] took around 2-8 minutes to image. On the newer drives, the imaging process took significantly longer with some images requiring 49 minutes each point.

Next, it is nearly infeasible to be able to recover any pattern of interest on the drive unless this is known in advance. It may not be too difficult to locate and image something such as the MFT (master file table) for the drive, but a file located at an unknown location on the drive would prove at the least a prohibitive exercise to find using any MFM technique.

Extrapolating this (and forgetting that an 80GB drive from 2006 does not compare in the resolution requirements of a 1Tb drive from 2008) it would be expected that a complete image of a 1 TB hard disk platter would take around 89 years to completely image using an MFM based technique. This is also ignoring the fact that I do not have an ion beam milled tip for a MFM at my disposal. This means that I could not obtain the resolution to scan a 1Tb platter even if I did have the lifetime to spare. (C. Tse, and I.D. Mayergoyz calculated that it would take over 10 years to image a 160GB drive using an MFM).

Dave Kleiman has noted that if the proper ion beam milled tip for a MFM were available and we could find a volunteer with nothing to do for the next 89 years (any of you have the next 89 years free, please contact him right away). Of course, 10 years from now there may very well be new techniques and process that could reduce the time necessary drastically.

Spin-Stand Microscopy

There is however another technique that could be used for whole platter imaging that do not suffer the limitations posed by MFM based techniques. Most significantly, Spin-stand microscopy is an imaging method where imaging is performed ex-situ on the disk platter which is mounted on a on a spin-stand. This method is far faster than any other form of microscopy as well as being non-invasive. It also has the capability to provide for the nanoscale resolution of the platter through a combination of track-wise and cross-wise sector analysis and reconstruction.

If a severely damaged drive platter needs to be examined and forensically reconstructed, Spin-stand microscopy (SSP) is the only viable option for high density drives. In addition, SSP does not introduce scanning induced hysteresis effects and incorporates the ability to use spatial averaging to minimize media noise.

SSP does not provide more than a stochastic calculation of the previously encoded data from an overwritten value. Hence, it cannot be used to recover data following an overwrite (as was determined using an MFM). The primary advantages of SSM is that it is far simpler to locate the position of a particular track on the disk platter and it is feasible to image an entire platter using this technique. What this technique does offer is the ability to image a drive in weeks rather than years.

Where this is valuable is in the recovery of data that is NOT overwritten. SSM techniques could be used to recover from a damaged drive for instance. When imaging an intact (undamaged) platter, SSM has an error rate in the order of 1 error per 1 million reads (this is consistent with the native channel read error rate for most drives before the ECC algorithm is applied to the data). This error rate increases significantly where damaged tracks exist and fails at a fracture boundary, but can be used to provide a significant level of recovery from damaged platters. Even when the platter has been broken and reconstructed, a significant amount of information can be recovered. Of course, the more severe the damage, the lower the percentage of data recovery that can be produced by the SSM technique.

This stated, the practice of drilling a small hole in a drive platter can result in minimal damage to the platter itself. In the case where this process does not shatter the platter, a recovery rate of over 99% of data can be achieved. Shattering the platter will not only add the requirement to reconstruct a “jigsaw puzzle” of immense complexity, but will also result in significant data loss. In this event, recovery can be as low as 20% (no sequentially) of the data on the platter (assuming that the entire platter has been completely – and accurately – reconstructed). The significance of this is that a single complete wipe of a hard disk drive is far more effective then drilling a hole in a drive platter or even hitting the drive casing with a hammer. The cost and time associated with reconstructing a shattered drive is in itself economically prohibitive and would limit nearly any recovery efforts.

Using track-centering, track-following, ISI-removal, data detection, and data decoding techniques that have been developed [2,3] and tested, ex-situ spin-stand based forensic techniques are likely to become more widely used in the forensic imaging and recovery of hard disk data in the future. In particular, these techniques are likely to become an integral step in the recovery of economically valuable damaged drives.

Note: SSM uses a variety of Hilbert transforms to image and recover hard disk data independent of the native write channel. The Fourier transform representation of the 2-dimensional Hilbert transform is calculated in order to emphasize the distinctive scaling features of the 2-dimensional Hilbert transform.

References and Further Reading

If you are interested in learning more on this subject, please have a read of the following papers.

[1] Craig Wright, Dave Kleiman, Shyaam Sundhar R. S.: Overwriting Hard Drive Data: The Great Wiping Controversy. ICISS 2008: 243-257

[2] C. Tse, C. Krafft, I.D. Mayergoyz, and D.I. Mircea, “System and Method for High-Speed Massive Magnetic Imaging on a Spin-Stand,” US Patent 7,005,849 (2006).

[3] I.D. Mayergoyz, C. Tse, and C. Krafft, “Method for Intersymbol Interference Removal in Data Recovery,” US Patent 7,002,762 (2006).

[4] B. Wilson, S. Wang, and A. Taratorin, “Generalized method for measuring read-back nonlinearity using a spin stand,” J. Appl. Phys., 81, 4828 (1997).

[5] P. Dhagat, R.S. Indeck, and M.W. Muller, “Spin-stand measurements of time and temperature dependence of magnetic recordings,” J. Appl. Phys., 85, 4994 (1999).

[6] A. Schultz, D. Louder, M. Hansen, C. DeVries, and J. Nathe, “Correlation of magnetoresistive sensitivity mapping (MSM) with spin stand performance,” IEEE Trans. Magn., 35, 2571 (1999).

[7] J. Moreland and P. Rice, “High-resolution tunnelling-stabilized magnetic imaging and recording,” Appl. Phys. Lett., 57, 310 (1990).

[8] R.D. Gomez, A.A. Adly, I.D. Mayergoyz, and E.R. Burke, “Magnetic field imaging by using magnetic force scanning tunneling microscopy,” Appl. Phys. Lett., 60, 906 (1992).

[9] R.D. Gomez, A.A. Adly, I.D. Mayergoyz, and E.R. Burke, “Magnetic force scanning tunnelling microscope imaging of overwritten data,” IEEE Trans. Magn., 28, 3141 (1992).

[10] R.D. Gomez, E.R. Burke, A.A. Adly, I.D. Mayergoyz, J.A. Gorczyca, and M.H. Kryder, “Magnetic force scanning tunnelling microscopy of high density recording,” J. Appl. Phys., 73, 6180 (1993).