Poster: Blue Note - How Intentional Acoustic Interference Damages Availability and Integrity in Hard Disk Drives and Operating Systems

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***Abstract*—Intentional acoustic interference causes unusual errors in the mechanics of magnetic hard disk drives in desktop and laptop computers, leading to damage to integrity and availability in both hardware and software such as file system corruption and operating system reboots. An adversary without any special purpose equipment can co-opt built-in speakers or nearby emitters to cause persistent errors. Our work traces the deeper causality of these risks from the physics of materials to the I/O request stack in operating systems for audible and ultrasonic sound. Our experiments show that audible sound causes the head stack assembly to vibrate outside of operational bounds; ultrasonic sound causes false positives in the shock sensor, which is designed to prevent a head crash.**

The problem poses a challenge for legacy magnetic disks that remain stubbornly common in safety critical applications such as medical devices and other highly utilized systems difficult to sunset. Thus, we created and modeled a new feedback controller that could be deployed as a firmware update to attenuate the intentional acoustic interference. Our sensor fusion method prevents unnecessary head parking by detecting ultrasonic triggering of the shock sensor.

***Keywords*—hard disk drives, embedded security, hardware security, denial of service.**

I. Introduction

Availability is the most important security property of a consumer hard disk drive (HDD). Without availability, it is difficult to meaningfully consider preservation of security properties such as confidentiality and integrity. Our work explores to what extent an adversary can intentionally damage HDDs with malicious audible and inaudible acoustic waves (Figure 1) and what are the limits of defenses.

Magnetic HDDs remain common [1] because of the long tail of legacy systems and the relatively inexpensive cost for high capacity storage. However, sudden movement can damage the hard drive or corrupt data because of the tight operating constraints on the read/write head(s) and disk(s). Thus, modern drives use shock sensors to detect such movement and safely park the read/write head. Previous research has indicated that loud audible sounds, such as shouting or fire alarms, can cause drive components to vibrate, disturbing throughput [2], [3], [4], [5]. Audible sounds can even cause HDDs to become unresponsive [6].

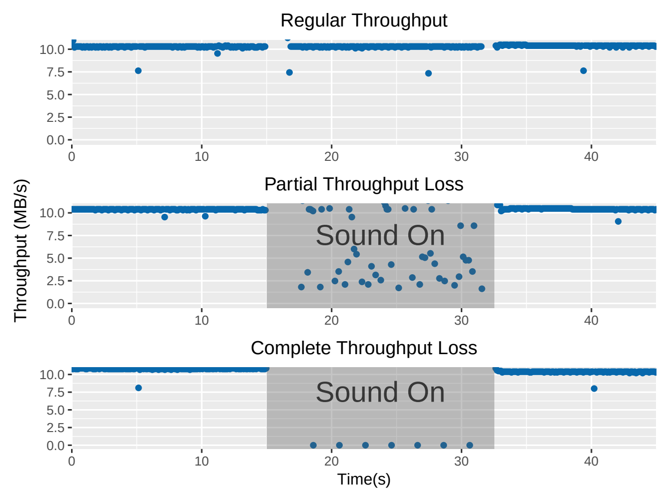

Fig. 1. Vibration can interrupt disk I/O. Three plots show a Western Digital Blue WD5000LPVX drive under normal operation (top), partial throughput with vibration induced by a 5 kHz tone at 115.3 dB SPL (middle), and halting of writes with 5 kHz tone at 117.2 dB SPL (bottom).

What remains a mystery is *how* and *why* intentional vibration causes bizarre malfunctions in HDDs and undefined behavior in operating systems. In our work, we explore how sustained, intentional vibration at resonant frequencies can cause permanent data loss, program crashes, and unrecoverable physical loss in HDDs from three different vendors. We also propose, simulate, and implement several defenses against such attacks on HDDs. Moreover, our research addresses the gap in knowledge in how ultrasound affects HDDs by triggering the sensor, a different causality from audible interference. Our contributions explore the physics of cybersecurity [7] for availability and integrity of systems that depend on hard disk drives:

- **Physical Causality:** How intentional audible and ultrasonic sounds cause physical errors in hard disk drives.
- **System Consequences:** How intentional physical errors in the hard disk drive lead to system level errors.
- **Defenses:** We simulate, implement, and propose defenses that can prevent damage to availability.

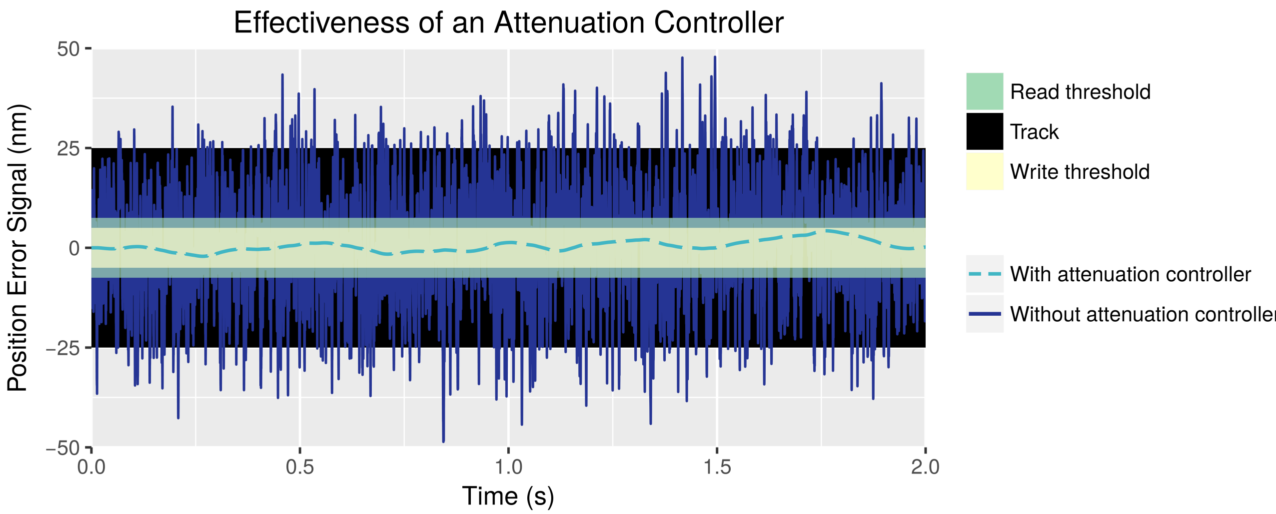

Fig. 2. Simulated position error variation for a 7.5 kHz attack. Our proposed attenuator controller reduces position error to within the read/write fault thresholds (15% and 10% of the track respectively). The defense allows the hard disk drive to function normally even while under attack.

II. Contributions

Physical Causality: Our component-level experiments and simulations provide evidence attributing the two root causes of the hard disk drive errors. The first root cause of hard disk drive errors is vibrating the read/write head(s) and the disk platter(s) at sufficient amplitudes. An attacker would use resonant frequencies of HDD components, typically in the audible range, to force the read/write head outside of normal operating bounds and causing drive error. With this method, throughput can be reduced anywhere between 0% to 100%. Reads from disk are harder to disturb than writes to disk.

Vibration can alter the HDD shock sensor's output, causing a drive to unnecessarily park its head. Experiments show that a drives's throughput loss caused by tricking the shock sensor have different qualities than the first causality. This method is typically triggered by ultrasonic waves, Due to throughput loss being caused by a binary decision in the firmware, throughput is either unaffected or fully lost. Lastly, vibration amplitude is similar for reads from disk and writes to disk.

System Consequences: Our case studies show that an attacker can use the effects from hard disk drive vulnerabilities to launch system level consequences such as crashing Windows on a laptop using the built-in speaker and preventing surveillance systems from recording video. We delve into the details of the Windows and Linux operating systems to uncover the root causes of the crash in the I/O request stack. Timeouts in Windows and Linux drivers caused by interference render the operating system render the system unable to communicate with the drive, even after the interference subsides. In addition, statistics taken from experiments indicate that acoustic interference may cause significant numbers of bad sectors in disks. Bad sectors may result in permanent data loss.

Defenses: We simulate, discuss, and implement defenses against both hard disk drive vulnerabilities. In our simulation, we show how a new feedback controller can attenuate the physical effect on the head stack assembly. We implement and evaluate noise attenuating materials as a defense. Finally, we propose sensor fusion as a means to detect malicious acoustic signals, allowing the drive to operate when attacked by ultrasonic signals.

III. Conclusion

Adversaries without special purpose equipment can cause errors in the hard disk drive using either audible or ultrasonic acoustic waves. Audible waves vibrate the read/write head and platters; ultrasonic waves alter the output of the HDD's shock sensor, intentionally causing the head to park. These errors can lead to operating system level or application level consequences including persistent corruption and reboots. Defenses include mitigating attacks in vulnerable frequency bands with attenuation controllers, using sensor fusion to detect attacks, and noise dampening materials to attenuate the signal.

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