TOSHIBA

Technical Review

Large-Capacity, High-Performance 3.5-inch HDDs for Surveillance Camera Systems Applying SMR Technologies

Accompanying the ongoing expansion of the surveillance camera market, strong demand has arisen in recent years for large-capacity, high-performance hard disk drives (HDDs) for surveillance camera systems including surveillance digital video recorders and surveillance network video recorders.
In response to this market demand, Toshiba Electronic Devices & Storage Corporation has released the DT02-VH series of 3.5-inch shingled magnetic recording (SMR) HDDs for surveillance camera systems. The DT02-VH series offers the following features: (1) a large storage capacity of 2 Tbytes/platter and (2) high-performance capability that makes it possible to connect up to 64 cameras through direct recording of video data simultaneously sent from multiple cameras to the SMR area on the disk without using a media cache, in addition to a conventional magnetic recording (CMR) area provided on the disk to directly record system data having a small data size.

1. Introduction

As the resolution of video data increases and the image processing technology using artificial intelligence (AI) progresses, surveillance camera systems are becoming increasingly entwined with people's lives, driving market expansion particularly in China. The volume of data generated by surveillance cameras is growing owing to the increase in resolution while demand is increasing for surveillance camera systems capable of recording multiple video streams simultaneously. This is spurring the need to increase the capacity of HDDs for digital video recorders (DVRs) and network video recorders (NVRs) deployed in surveillance systems.
Under these circumstances, Toshiba Electronic Devices & Storage Corporation has developed the DT02-VH series of 3.5-inch SMR HDDs. The DT02-VH series provides an optimized capability to enable efficient and simultaneous recording of multiple video data streams from cameras without using an intervening media cache (MC). High-end surveillance camera systems require HDDs with outstanding performance to connect as many as 64 cameras and storage capacity. The DT02-VH series of SMR HDDs satisfies these requirements by reserving part of a disk as a CMR area where system data, which are small in size, are directly written.
This report describes the challenges in achieving the SMR performance required for surveillance HDDs as well as the technologies used to overcome these challenges for the development of the DT02-VH series.

2. Challenges for SMR HDDs for surveillance camera systems

2.1 Firmware specifications

Designed to work with an existing filesystem, DVRs and NVRs for surveillance camera systems require HDDs compatible with the existing command sets. In addition, drive-managed (DM) firmware is required to replace the CMR HDDs of existing surveillance camera systems with large-capacity SMR HDDs.
With DM firmware, data streams from the host system are buffered in a media cache (MC), an area on a magnetic disk allocated during HDD operation. When the HDD runs short of free MC space, the data in the MC are written to a band, or a collection of overlapped tracks that are sequentially written (**Figure 1**). If this occurs as a result of a continuous HDD operation for an extended period, MC-to-band data transfer occurs frequently, incurring degradation of random-write performance[1]. This is one of the challenges that we have tackled.

2.2 Storage usage specific to surveillance camera systems

A surveillance camera system records video data streams from many cameras simultaneously in a single HDD or redundant arrays of independent (inexpensive) disks (RAID). This is generally performed as follows. The disk space is managed as a collection of clusters, i.e., a unit of logical block address (LBA) space of several hundreds of Mbytes to one Gbyte. Each cluster is assigned to one camera. A video data stream from a given camera is written sequentially from the beginning of a cluster. When it becomes full, a new cluster close to the current one is allocated to that camera. This process is repeated to record hours of video (**Figure 2**).

Demand is growing for solutions for increasing the number of cameras that can be connected to a surveillance camera system. Nowadays, a single HDD is required to record video data streams from 32 to 64 cameras simultaneously.
With the progress of AI-based image processing technology, the latest surveillance camera systems are capable of analyzing live video from cameras and recording the detected pedestrians and vehicles as image data. These surveillance camera systems need to record a multitude of small image data together with large video data.

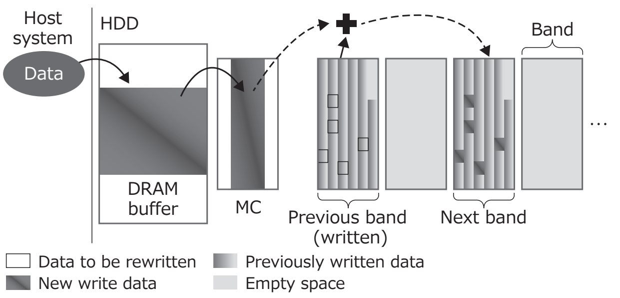

Figure 1. Data rewriting procedure in drive-managed SMR (DM-SMR) HDD—An MC is internally utilized for random writes that require rewriting of existing data.

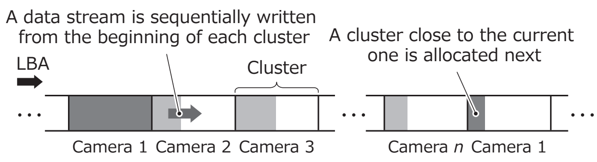

Figure 2. Example of video data arrangement in surveillance camera system—A video data stream from a given camera is written from the beginning of a cluster. When the current cluster becomes full, a cluster close to it is allocated next.

3. Overview of the DT02-VH series

Table 1 shows the main specifications of the DT02-VH series of 3.5-inch surveillance HDDs. To develop the DT02-VH series, we have improved the recording layer of the magnetic disk and the performance of read-write heads to increase the linear recording density while using SMR to increase the track density. Whereas the preceding five-platter MD04-V series provides a storage capacity of 5 Tbytes (1 Tbyte per platter), the three-platter DT02-VH series provides a storage capacity of 6 Tbytes (2 Tbytes per platter). The DT02-VH series incorporates DM firmware using existing HDD commands. This firmware is tailored to achieve high multi-stream performance, supporting connections of up to 64 surveillance cameras. The subsequent sections describe the technologies used to develop the DT02-VH series.

Characteristic	Specification	
	DT02ABA600VH	DT02ABA400VH
Type of SMR firmware	DM	
Number of cameras supported	Up to 64	
Interface and speed (Gbits/s)	SATA-3.3, 6	
Storage capacity (Tbytes)	6	4
Number of platters	3	2
Number of magnetic heads	6	4
Buffer size (MiB*)	256	
Rotation speed (rpm)	5,400	
Maximum continuous data transfer rate (MiB/s)	176.4	
MTTF (h)	1,000,000	
Power consumption (active idle)	2.81	2.33
External dimensions (mm)	101.85 (W) ×147.0 (D) ×26.1 (H)	
Weight (max) (g)	680	640

* Mebibytes: 2^{20} bytes
MTTF: mean time to failure SATA: Serial Advanced Technology Attachment

Table 1. Main specifications of DT02-VH series 3.5-inch HDDs for surveillance camera systems

4. Video data recording method used by the DT02-VH series

4.1 SMR using spare bands and bypass writes

The DT02-VH series records data in SMR format in units of a band. An unused area is inserted between bands to prevent a write to a given band from corrupting data on an adjacent band. A collection of multiple bands is called a band group. Although all the bands in a band group have the same capacity, the capacity of a band depends on whether it is located in an outer or inner track. Each band group has one spare band, a work space where no valid data exist (**Figure 3**).
Data from the host system are buffered in a DRAM buffer first. The buffered data are then transferred to a spare band in one of two ways, depending on the data size:
Method (a): Updating part of a band
Data in the DRAM buffer are first written to the MC. These data are combined with the existing data in the band to be updated and moved to a spare band. Subsequently, the firmware flags the original band as a spare band and the previous spare band as a valid band.
Method (b): Updating all the data in a band
When a large sequential data stream comes from the host system, data in the DRAM buffer are written directly to a spare band. When the end of the spare band is reached, the firmware flags the band to be updated as a spare band and the previous spare band as a valid band. This process is repeated.
Method (b), which transfers data directly to a band without using the MC, is called a bypass write. Although bypass writes can only be used to update all the data in a band, they are completed with minimal operation. Since most of the video data from a surveillance camera system are sequential, the key to improving the write performance lies in recording as much data as possible using bypass writes.

4.2 Bypass writes using free bands

As described in Section 2.2, a surveillance camera system records video data streams from many cameras in nearby bands simultaneously. To process these data efficiently, it is necessary to bypass-write nearby bands (i.e., multiple bands in the same band group) simultaneously. Section 4.1 described an example of a bypass write using a spare band. A downside of this method is that only one stream of bypass writes can be performed for a given band group. Therefore, instead of spare bands, the DT02-VH series is designed to allow the use of free bands (i.e., the bands that hold obsolete data and can be overwritten) so that multiple bypass writes to a given band group can proceed simultaneously (**Figure 4**)[(2)].
First, let us look at how a stream of bypass writes is performed for a band group (Figure 4(a)). The letters a to j denote existing data stored in each band whereas [S] and [X] signify spare and free bands, respectively. The following paragraphs describe the procedure for sequentially updating the consecutive data of b to g with B to G.
Step 1. B is written to the MC. At this point, b becomes obsolete, making its retention unnecessary. Therefore, the band in which b was held is flagged as a free band [X] so that it can be used to record other data.
Step 2. C is written to [X]. This is performed as a bypass write while leaving existing data c intact. So, the existing data are not lost even if the bypass write is terminated prematurely. When the writing of C is completed, the band in which c was held is flagged as a free band [X].
Step 3. D, E, F, and G are sequentially written in the same manner as Step 2.
Step 4. B in the MC is transferred to [S], and [X] is flagged as a spare band [S]. This means that [X] is deleted simultaneously.
Next, let us look at how multiple bypass writes are performed for the same band group (Figure 4(b)). In this example, two streams of bypass writes (B-C-D and G-H-I) are performed simultaneously. This process uses two free bands, [X] and [Y], generated as a result of writing B and G to the MC, in order to bypass-write C and H simultaneously. Since any number of free bands can be generated when a band of data is written to the MC, three or more streams of bypass writes can proceed at the same time. Bypass writes are performed band by band. Since the band size has no bearing on the cluster size of a surveillance camera system, the leading and trailing ends of video data are not large enough to fill a band. Therefore, these fraction data are combined with fraction data before being written to a band in the same manner as Method (a) described in Section 4.1.
In this way, the DT02-VH series perform bypass writes using free bands to cater to the characteristics of video data streams from a surveillance camera system.

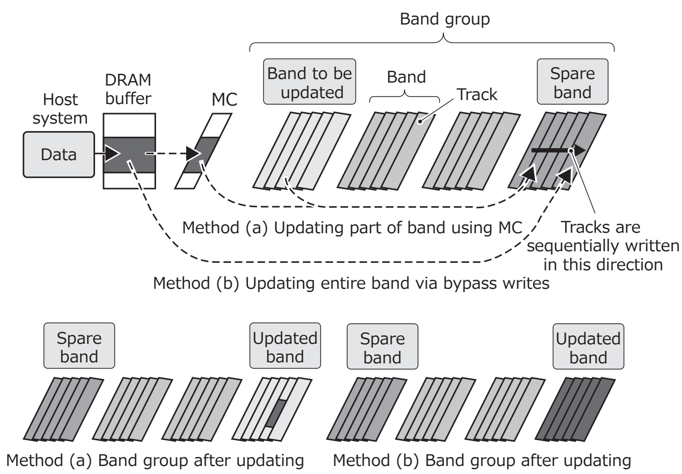

Figure 3. Data updating operation using spare bands—New data are written to a spare band. Data updating occurs safely as the firmware flags the updated band as a spare band and the previous spare band as a valid band.

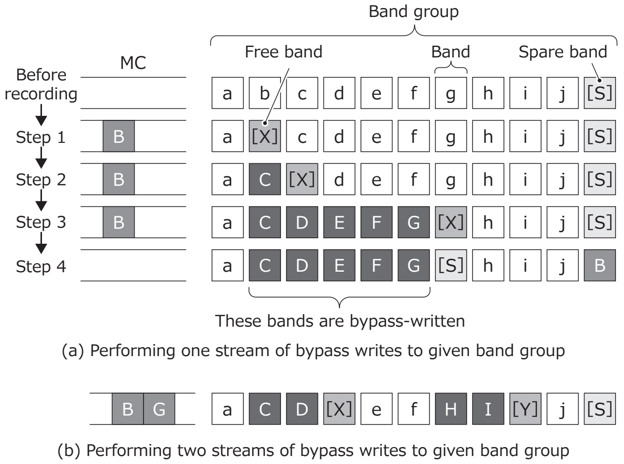

Figure 4. Bypass writing operations in band group using free bands—Free bands are generated when data are written to the MC. Bypass writes are performed using free bands.

5. Recording system data in CMR format

In addition to video data, a surveillance camera system records management and analysis data (hereinafter collectively referred to as "system data") simultaneously. System data consist of a multitude of small data blocks. Since system data are random in nature, they are unsuitable for DM-SMR. However, the amount of system data is increasing because of the ever-increasing performance of surveillance camera systems. To record system data of a surveillance camera system efficiently, the DT02-VH series provides a CMR area, which is located in a fixed LBA range to suit their locations.

Although random data can be written directly to the CMR area, it is more important to guarantee the integrity of system data than that of video data. In order to ensure the integrity of system data, the surveillance camera system often requests an HDD to flush-write all the unwritten data using the Flush Cache and Flush Cache EXT commands. Since typical HDDs cache the write data in a DRAM buffer, many of the write data remain in the DRAM buffer, waiting to be written to a disk. Since there is a large amount of data to be flush-written, this flush-write operation must be performed at high speed to record video data streams stably.

In response to a flush-write request, the DT02-VH series writes all the unwritten data to a disk immediately. At this time, the write operation destined to the SMR area can be completed in a small amount of time because the write data are cached in the MC. In contrast, the writes to the CMR area require a lot of time because the data destined to the CMR area entail many seek operations and rotational delays. This is inevitable even if these writes are optimized in the order of write operations. To resolve this issue, the DT02-VH series provides an area where the data destined to the CMR area are temporarily saved (**Figure 5**). These data are written to the temporary saving area in response to a flush-write request to speed up a flush-write operation.

6. Conclusion

The DT02-VH series of 3.5-inch SMR HDDs for surveillance camera systems provides a large capacity of 2 Tbytes per platter owing to an increased recording density. In addition, the DT02-VH series incorporates firmware optimized for multi-stream surveillance environments to support connections of up to 64 cameras. With the prevalence of 4K (3,840×2,160 pixels) and 8K (7,680×4,320 pixels) ultra-high-definition cameras, the volume of data generated by a surveillance camera system is expected to increase, driving a further increase in the capacity of surveillance HDDs. Surveillance camera systems are also incorporating various innovations to take advantage of the characteristics of SMR HDDs. Therefore, demand for SMR HDDs for surveillance camera systems is expected to increase.

In response to the growth of the surveillance HDD market, we will continue to increase the capacity of surveillance HDDs to satisfy customer requirements, contributing to the development of information infrastructure.

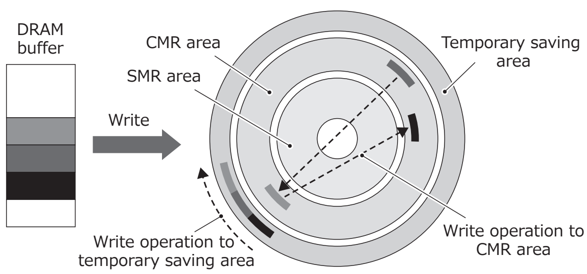

Figure 5. CMR and temporary saving areas on disk—The CMR area is suitable for recording system data. The DT02-VH series provides an area where they are temporarily saved in order to speed up flush-writes.

References

(1) Shimomura, K. 2019. "Large-Capacity HDDs Applying SMR Technology for Data Centers." Toshiba Review: 74(6): 12–16. Accessed August 2, 2021. https://www.global.toshiba/content/dam/toshiba/migration/corp/techReviewAssets/tech/review/2019/06/74_06pdf/a04.pdf.

(2) Toshiba Corporation, Haga, T., Tanaka, H. 2016. "Disk storage device and method." Japanese Patent No. 5951472. Published July 13, 2016.