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The use of digital video recorders (DVRs) for capturing digital video files for use in both The Observer and Ethovision

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Before switching a laboratory from analog to digital, for the recording of video files for use in Noldus software such as Ethovision and The Observer, researchers need to proceed with caution. There are obvious advantages in moving to digital recording for behavioral work, including increased storage capacity; no requirement to purchase video tapes; immediate search by date, time, or event; digital images are of higher quality; ability to view study sites remotely by Internet connection; and "smart" features, such as motion detection. But before you throw away your time-lapse video recorders, time code generators, and video multiplexors, there are some important cautions to take account of. Some research groups have bought digital surveillance systems on the assumption that they work with Ethovision and The Observer, only to be disappointed. The vast majority of systems depend on proprietary compression software that must then be converted to work properly in Ethovision or The Observer.

The purpose of this article is to give some insight into digital video recording technology used in security systems to individuals who study behavior. The purpose is to caution scientists who are contemplating switching to digital surveillance systems. At first glance, these systems would appear very practical to the behavioral scientist, but the vast majority of systems available are designed for security purposes, not for studying animal behavior, and may not be compatible with Ethovision and The Observer. The technology is very new, and although many advantages are touted over traditional analog recording (Table 1), scientists who have invested substantially in these systems have reported difficulties, particularly regarding compatibility with behavioral analysis software such as Ethovision or The Observer. The problem is that security systems have multiple viewing functions required for surveillance work but they generally contain proprietary compression and limited video export capabilities. As a result, most systems export digital video to large files that are in a format that is difficult for behavioral software to use. In many instances, if a research group wishes to utilize digital video, it may be better to continue to use traditional methods of analog recording and to digitize the video later, using a video capture device (either a PC card or an external hardware device) that converts the analog signal to a digital format. Other systems may be available that could be adapted for research use, such as products from the movie industry, but they are likely cost prohibitive and are beyond the scope of this article.

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What Is a Digital Video Recorder (DVR)?

Digital video recorders (DVRs) work in a fashion similar to that of a video cassette recorder (VCR), but they rely on hard drives to store digital data, instead of video tapes that record analog data. Digital video recorders can record a video input stream from a variety of sources (Webcam, capture card, video camera, or television broadcast) by recording the video data and storing the data on a hard drive. DVRs have all of the same functionality of VCRs (recording, playback, fast forwarding, rewinding, and pausing), plus the ability to instantly jump to any part of the recording without having to rewind or fast forward the data stream. The first DVRs that appeared on the market were mechanical devices that resembled conventional VCRs, with similar function keys, making them very familiar and less intimidating, but the shortfall was that a price was paid in terms of functionality. These devices are still available but are now also known as personal video recorders (PVRs). The market demanded more, and soon personal computer (PC) based DVR systems became available. PC-based DVR systems are complete hardware/software computer-based systems incorporating video capture, video multiplexing, video/audio recording and playback,

Table 1
Advantages of DVR Versus Analog Recording

Characteristic	Digital	Analog
Search ability	Instant by date, time, or event	Manual search
Storage capacity	Months of footage, high capacity, no degradation of quality over time	Requirement to buy videotapes, quality degrades over time
Duplication	No signal or quality loss on recording, copying video is virtually instant	Video signal degradation on rerecording or duplication, copying video is in real time
Image quality	High quality	Poor image quality
Remote monitoring	View multiple locations over Internet	Limited monitoring capability
Intelligent features	Motion detection, remote notification	No intelligence

video display, and remote video access via modem, Internet, or local area network. More recently, advances have been made with high-end digital non–PC-based DVRs that can duplicate the functions of a PC-based DVR. These embedded DVRs do not use a Windows operating system and contain no software at all on the hard disk(s). All applications are contained, or *embedded*, in firmware (software encoded on chips). Mobile DVRs are embedded systems that were originally developed for use in vehicles. They incorporate antishock and antivibration mountings and generally have 12-V DC power inputs. At the heart of any DVR system is a video capture card or a similar device. They are called *capture* cards because they "capture" and record the video (encoding), but they are also responsible for playback and display of the video on screen (decoding). The other component most often includes some kind of CCTV (closed circuit television) camera. Digital video recorders are sophisticated integrated systems composed of a combination of hardware components, software programs, and subassemblies. These systems are most commonly used for security monitoring purposes via video surveillance and should not be confused with set-top consumer cable boxes such as TiVo. Although these are also referred to as DVRs, the purpose and function of the two systems are different.

Problems With Implementing Security-Based Systems for Behavioral Research

In purchasing a surveillance system, the first priority should be to assess and understand your needs. It is imperative that the system accomplish exactly what you want it to do; otherwise, the capital expenditure required to purchase the system will be wasted. The problem is that most of the companies and individuals selling these systems are unfamiliar with the unique application of the DVR for behavioral observation and simply assume that the system will work. From a hardware perspective, the systems seem simple enough; most comprise two main components: cameras and a DVR. However, within each of these two components, there are a number of choices to consider, with prices varying significantly. In April 2005, the International Security Conference and Exhibition West was held in Las Vegas. The conference was attended by 21,000 industry participants with 825 exhibitors. Of the exhibitors, one third (246) were promoting some combination of camera/DVR system for security monitoring. Generally, all of them are custom-built systems, and consequently, there is a lack of standardization between products. This especially raises problems for the scientist who is trying to select the appropriate digital recording system to meet specific behavioral observation needs. Some problems encountered with implementing security-based systems for behavioral research are the following: Specific systems often work with only certain cameras; the quality of the recorded video is less than optimal; recorded and display speeds are not what has been stated; they are unable to play back video on computers or machines other than the one on which it has been recorded; the numbers of days of storage is less than what has been specified; no local support is available for the product; the file format, when decoded, is not compatible with Ethovision and The Observer; and frames are intermittently dropped, due to processor use, but the audio is recorded continuously, resulting in video and audio that is out of sync and virtually unusable.

Understanding Compression Formats

Working with digital video requires a large amount of storage capacity, and digital video generally needs to be compressed before it can be stored. All companies provide some form of their own proprietary compression. Compression technology is based on mathematical algorithms. Compression is performed when an input video stream is analyzed and information that is indiscernible to the viewer is discarded. It is actually a case of compression and decompression: Information is compressed to travel down the network and then decompressed for transmittal when it comes out the other side—hence, the name *codec*. A video codec is software that can compress a video source (encoding), as well as play compressed video (decoding). Standards are set by the International Organization for Standardization—a nongovernmental organization that works to promote the development of standardization in order to facilitate the international exchange of goods and services and to encour-

age worldwide intellectual, scientific, technological, and economic activity—and the International Electrotechnical Commission, the international standards and assessment body for the field of electrotechnology. These two industry bodies recognize a number of standard compression formats, including MPEG-1, MPEG-2, MPEG-4, Morgan JPEG (MJPEG), Wavelet JPEG, H.264, and so forth. Manufacturers purchase a license to utilize one of these compression formats, but many attempt to "tweak" the format themselves, making the format unstable for use with either Ethovision or The Observer. AVI is especially problematic, but nevertheless, it is a format that many digital surveillance companies use. It is important to note that Ethovision does not support all formats of AVI (such as DivX) or MPEG-4. It is important to recognize that the market is changing fast and that new standards are rapidly emerging. Much of the information with regard to compression formats will likely be obsolete in 5 years. MPEG-4 has emerged as one of the new standards for both multimedia and Web compression. MPEG-4 is based on object-based compression; individual objects within a scene are tracked separately and compressed together to create an MPEG-4 file. This results in efficient compression that is very scalable, from low bit rates to very high. It also allows developers to control objects independently in a scene and, therefore, introduces interactivity. As a result, it has become a popular format in the digital surveillance industry and will likely become a new standard in the future. MPEG-4 is now available and compatible with The Observer XT that has recently been released from Noldus. However, it is important to reiterate that it is still not compatible with Ethovision. In our experience, for the majority of researchers, it is best to stick with either MPEG-1 or MPEG-2 in order to maintain compatibility with behavioral software packages.

MPEG-1. MPEG is a file format for compressing full-motion digital video that was produced by the Moving Picture Expert Group of the International Standards Organization. It was originally designed for up to 1.5 Mbit/sec. For the last couple of years, MPEG-1 has been the standard for the compression of moving pictures and audio. This format was primarily used for CD-ROM video applications, and it is still a popular standard for video for use on the Internet, transmitted as *.mpg files. MPEG-1 is the standard of compression for VideoCD, the most popular video distribution format throughout most of Asia. Of interest, Level 3 of MPEG-1 is also the standard of digital compression for audio, better known as MP3. Although MPEG-1 produces better results than do QuickTime (.mov) and AVI, the MPEG-1 standard provides a video quality that is slightly below that of traditional VCR analog recording. The advantage of MPEG-1 is that the files are relatively small (about 10 MB/min) and, therefore, take up less storage space. A further advantage is that MPEG-1 software decompression comes standard on the Windows operating systems, so it will work on a variety of computers. If continuous observation is an important consideration, or if observation is going to take place over a long period of time, and quality may not be imperative, this is a very useful format to use.

MPEG-2. The MPEG-2 format offers higher video quality than does MPEG-1, but the downside is that the file size increases dramatically (about four times the size, or approximately 40 MB/min). MPEG-2 is the standard on which most digital television set-top boxes and commercial DVD compression are based. Although it is based on MPEG-1, it was designed for the compression and transmission of digital broadcast television. The advantage of MPEG-2 is the improved quality, sufficient for all the major television standards, including NTSC. The most significant improvement over MPEG-1 is its ability to compress interlaced video. MPEG-2 scales well to HDTV resolution and bit rates, which essentially eliminates the need for MPEG-3. In terms of quality for behavioral observations, MPEG-2 is adequate for the vast majority of behavioral researchers.

Considerations of storage. The primary advantage of digital video is that it is easier to manipulate with Noldus software than are analog sources; also, hardware prices have decreased rapidly in recent years. However, digital video still requires considerable storage capacity and needs to be compressed before it can be stored on a disk medium. Most DVR systems have a lot of flexibility in terms of file storage. Often, files can be stored on large hard drives or even stored on the departmental server over a network. Many systems included CD/DVD burner software, allowing the end-user to burn the files to a CD or DVD for archival storage, and some miniaturized systems are designed to work with memory sticks. Due to the large size of the digital video files, most users will want to store to a DVD format. However, there are multiple DVD formats. DVD stands for Digital Versatile/Video Disc, DVDR stands for DVD Recordable, and DVDRW for DVD ReWritable. This medium looks very similar to regular audio/music compact discs or DVD-Video discs that are sold by the recording and movie industries. There are three competing DVD recording standards or formats; DVD-R/DVD-RW (supported by the DVDForum), and DVD+R/DVD+RW (supported by the DVD Alliance), which have pretty similar features and are compatible with many standalone DVD players and recorders, whereas DVD-RAM has less player and recorder compatibility but better recording features. It is important to determine which format is compatible with the individual DVR under consideration. DVD-RAM has the best recording features, but it is not compatible with most DVD-ROM drives and DVD-Video players. This format should be considered more as a removable hard disk (this format is supported by the DVDForum).

As was mentioned previously, digital video needs to be compressed before it is stored on a disk medium. With many DVR systems on the market, you can set the sound and image quality of the resulting media file. However, the higher the quality, the larger the file. Thus, the highest quality of images and sound require a large amount of space on the disk. In practical terms, most users select their quality with the capacity of their long-term storage media in mind. For example, with an MPEG-1 of 10 MB/min, you can fit about 1 h of video onto one CD (700 MB).

Both DVD-R and DVD-RW support single-sided 4.37-GB DVDs (called DVD-5) and double-sided 8.75-GB DVDs (called DVD-10). Some disks are dual layered. A dual-layer writable DVD+R or DVD-R can hold 7.95 GB (called DVD-9), and dual-layered double-sided disks can hold 15.9 GB (called DVD-18).

Considerations about frame rate. An important consideration when analyzing specifications of a DVR system is to clarify *frame*, or *images*, per second. Many labs have reported that the frame rate promised has not been the same as the frame rate realized under laboratory conditions. The frame rate issue is very tricky. The fact is the speeds that manufacturers quote are usually the "maximum" obtainable, meaning those obtainable under ideal conditions, and do not take into account other functions that the PC, software, or video card might be processing simultaneously. There are an infinite number of ways of presenting these numbers, and the numbers can often be misleading. A standard in the marketplace is 30 frames/sec, which is considered to be real-time/real-motion video, but that is for a single video stream. For example, if four cameras are recording simultaneously, all in real-time/real-motion video, 120 frames/sec with full unshared resources is required. It is very important that frame rate be clarified; for example, the manufacturer may be discussing the following: the total number of frames/images/sec for the entire card spread across all cameras (cumulative total); the total number of frames for each individual channel; the maximum frame capacity of the hardware, not taking into account software switching, simultaneous functions, and so forth (rated hardware capacity); the display speed; the recording speed; or a combination of all of the above.

Advantages of DVR

One of the immediate advantages of digital versus analog recording for behavioral observation is that digital video no longer requires special hardware for reading time codes, controlling the video, or displaying an image or multiple images on the monitor. Most DVR systems have software solutions that negate the need for many traditional hardware requirements in an analog-based system, such as time code generators, video signal splitting devices, or even time lapse video recorders. In most cases, the DVR can provide all of those things. The advantages and disadvantages of DVR and analog video are outlined in Table 1.

New features of DVR. The reality is that DVRs are part of a very young technology; new features are continually emerging, and the bar is being pushed higher every day. With constant demand for new features, a powerful foundation is required. But new features mean new unknown variables and accompanying problems.

It is important to remember that the software that is provided with the DVR system is the foundation of the system and at least as important as the hardware. At the heart of any good DVR software program is a solid database structure. Hardware components aside, the architecture of the software's database is the single most important part of the DVR. How the database stores the video files and what happens when multiple users simultaneously access the database are important issues that must be resolved. What happens when you have to search through thousands of files or conduct queries? How long does it take to convert or export the files from compressed files to files that the user can actually use? What file format will ultimately be used with the behavioral software package? These are all important questions that the end-user must be aware of.

Motion detection is an exciting new feature of many DVR systems. Motion detection essentially allows for a motion-detection–triggered record function or alarm. Motion detection is a very useful alternative to simple continuous recording. Often, continuous recording is used by behavioral scientists because they do not want to miss a behavioral activity or event that is difficult to detect with scan sampling. By recording only when activity is occurring, one can store significantly more video on the hard disk, but more important, the researcher does not waste time on playback watching when no activity is occurring. Often, the system can be preset to capture a brief time segment prior to the motion's occurring, which could be very useful data. Along with motion detection, many systems allow the user to specify an area within the field of view of a camera and perform a search for any motion that occurs within that zone, a useful feature that could be used to refine behavioral tracking with Ethovision.

Another useful advantage of DVR systems, in comparison with other alternatives, is the ability to monitor the system remotely over the Internet. In order to connect the DVR to the Internet from a remote location, generally all that is required is an IP address of the location where the DVR is situated. In addition, many systems not only allow one to remotely view cameras simultaneously, but also allow one to manage the main functions of the DVR as well. And finally, cameras can be locally or remotely controlled for panning, tilting, and zooming. It is important to caution the user, however, about the pitfalls of keeping a recording computer connected to the Internet. Often, automatic software updates, antivirus software, and other externally directed processes can reduce available processing from the CPU and may interfere with the file's being recorded.

The inclusion of diagnostic software, which constantly monitors different functions of the hardware and software of both the DVR and the server or other storage medium, is also very useful. If the diagnostic software detects any deviations from the established baseline criteria, the system can notify the system administrator that it has detected a problem. The inclusion of remote diagnostic software, which allows the research scientist or a technician to monitor system performance and diagnose and repair potential problems remotely, is also very useful. This feature could save on unnecessary service calls to the DVR's physical location, which may be thousands of miles away from support personnel.

Often, the ability to time/date stamp the data file is a feature built into many systems. In the future, it is very likely that additional data will be readily superimposed on the video files generated from DVR systems. Already

POS (point of sale) information is being included as embedded text on the video files in some DVR systems used for security surveillance in the restaurant industry. The ability to include additional data, such as physiological or environmental measures, will likely become standard features of many DVR systems in the future.

Important questions to ask about DVR. The biggest obstacle within the DVR industry that researchers need to be aware of is that a number of entities that were already in the security business in the last generation of CCTV technology have attempted to cross over into a world that is far removed from their core competence. DVR systems are primarily an information technology product. Nothing within the last generation of CCTV resembles this, nor does it lend itself to a knowledge base that is readily transferable. The last generation of surveillance equipment depended on mechanical analog-based products, which are, in essence, fixed machines. As this article has outlined, DVRs are sophisticated network appliances that are primarily software based. Many companies have entered this business with the best of intentions but have become quickly overwhelmed. With each new company that enters into the marketplace, another one goes out of business. Unfortunately, the number of assemblers and would-be manufacturers are in the thousands, and the number continues to grow. There are, however, a number of key questions that a researcher should ask the supplier when considering a switch from an analog to a DVR-based system:

What experience do they have with the product?

How long have they been in business?

If you have a problem who do you call?

How long does it take to get service?

Where are their service centers located?

Are the end files that are generated compatible with Noldus behavioral software?

In this article, we have attempted to cover the basics on the use of DVRs designed for security surveillance in behavioral research, how they work, and their components and software, as well as related concerns. On the basis of the facts presented in this article, we are hopeful that behavioral researchers will formulate the right questions before acquiring a new DVR-based system.

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