We have come a long way from the days of analog VCRs, Multiplexers and monitors. Digital video has changed the way we capture, display, manipulate and store an incident. These changes have not always been easy or inexpensive both economically and perceptively. At the beginning of digital video technology, the cost of storing the digital images on a hard drive was out of reach of many and the apparent quality questionable. However, with the invent of compression methods and the digital video technology improvements along with the plummeting cost of storage media, the digital video recording has became the wave of the future. To become familiar with this technology and better understand its uses we have to answer the following questions:

- What is digital video technology?
- What is Compression and why is it needed?
- What are different compression methods?
- What are Bitrate and Bandwidth?

Digital Video Technology

Digital video technology is based on converting an analog video into bits of 0’s and 1’s so that the PC can understand and process. This technology first appeared in the form of streaming data formats which appeared in crude form around 1990. Before the arrival of faster Pentium processors in the latter part of 1993, even the most powerful PCs were not able to capture images larger than an over-sized mailing stamp (160 x120 pixels). As faster processors became available and the consumer needs for digital video technology grew, many hardware manufacturers realized the need for more advanced technologies to digitize analog video for the use in different consumer markets. One of the fastest growing markets has been the conversion of analog CCTV to digital. This conversion or digitization of an analog signal is performed by a complex hardware known as the video capture card which converts each frame into a series of bitmapped images and transfers the information to the PC to process and manipulate.

To understand this process further we need to review a little background in analog video signal technology. The National Television Standards Committee (NTSC) established the standards for the Composite Video Signal used by TVs and VCRs in North America. This system uses 525 lines per frame, a field frequency of 60 Hz, 30 frames per second update rate and a YIQ color space. What do all of these numbers mean?

In order for an image to be displayed on an analog monitor, three beams (Red, Green, and Blue) paint one line across the screen from left to right. They then quickly fly back to the left side, skipping a line, then starts painting another horizontal line, and so on down the screen before jumping back to the top. This interlaced process produces one image field at a rate of 1/60th of a second (60 Fps). Once back at the top, the beams start the process again by filling in the skipped lines until all 525 files are filled in. Although there are 525 horizontal lines being drawn, only 480 lines are visible. The rest are used for text and do not contain any picture information. The entire drawing process is performed 30 times per second, thus 30fps update rate. The YIQ color space represents the luminance and chrominance of a video signal which corresponds to the brightness and color information of the video signal.
The process by which a capture card performs this conversion is extremely complicated and beyond the realm of this article. However, in its simplest form, in order to visually process an image, a capture card converts every peak and valley of an analog video signal into a series of 0’s and 1’s using a very sophisticated computer chip called an Analog-to-Digital Converter (ADC). This conversion process is called sampling. Sampling is the measurement of the value of the analog signal at regular intervals.

These values are then processed by another computer chip known as an encoder to provide a digital representation of the original analog signal. The more samples that are taken from the analog signal the higher the quality of the digital representation. The frequency with which the samples are taken from the analog signal and converted into digital is called sampling rate. This process is performed one horizontal line at a time and split into 640 sections also known as pixels (for NTSC). For each of these sections, the red, green, and blue values of the signal is calculated which generates the 640 colored pixels per line. The 640 pixels is derived from the 4:3 aspect ratio of a standard TV picture which is 480 visible lines times 4 and then divided by 3. The result of this conversion yields the 640 x 480 VGA signal that can be managed and displayed on a digital monitor by the PC without any additional special conversion. To display this digital signal back onto a standard analog TV set, the process has to be reversed using a Digital-to-Analog converter (DAC) to regenerate the original analog signal.

This signal conversion and display can be performed by the PC internal components without using too many resources. However, storing, analyzing or transmitting this digital information to a different location becomes a very difficult task for even the most sophisticated and most powerful PCs without managing its size. A single frame of a color image at 640x480 pixels will result in a file 900KB (Kilobyte) in size. With this file size, 24 hours of video at 30fps will require approximately 2.3 TB of hard drive space. This is not at all practical. So how can a Digital Video Recorder (DVR) manage to store weeks if not months of video at a time in a space much less than that? The simple answer is Compression.

**Compression**

In its simple form, compression is the art of removing unwanted data or empty space from a file without affecting the outcome. In the information world, the idea works great and the data is managed without loss. In the digital video world however, the results can sometimes be very disappointing. The technology behind video (and audio) compression is known as CODEC which stands as COmpression-DECompresion. There are many types of codec that have been developed and are in use today with
mixed results. In general, video compression is a tradeoff between the available disk space, the desired video quality, and the cost of necessary hardware to compress or decompress the video in a reasonable amount of time. Based on the market demand this could become a very difficult balancing act to perform. The compression technologies that produce the smallest file size have shown to have the most losses in the reproduction generating the least desirable video quality. This type of compression is known as LOSSY compression. LOSSLESS compression on the other hand is a type of compression that can reproduce an image almost as perfect and without any alteration in quality as the original image. However, this type of compression is rarely used because the reproduced image size is almost as large as the original image size, rendering it useless in digital video processing. Creating a balance between quality and size has been a struggle for the developers since the very beginning of compression technology. Some of the most commonly used compression formats in the DVR technology include M-JPEG, MPEG and H.264.

M-JPEG or Motion-JPEG short for Motion Joint Photographic/Picture Expert Group is a form of compression codec that processes digital video by compressing each individual interlaced field (60 per second) as a JPEG image. It was originally developed for use by PC multimedia applications but later replaced by more advanced formats. M-JPEG is now used by many portable devices with video-capture capability, such as digital cameras. M-JPEG is designed to take advantage of known limitations of the human eye, notably the fact that small color changes are perceived less accurately than small changes in brightness. Thus, it is intended for Compressing images that will be viewed by humans. Based on the standard composite video, the M-JPEG could achieve a 20:1 compression with little loss of image quality but with a larger storage requirement than many other standards.

MPEG (Moving Picture Expert Group) is the term used to describe a family of digital video compression standards developed by the group. MPEG generally produces better-quality video than competing formats and creating smaller file sizes. MPEG works by dividing the image into much smaller blocks and compressing it to form small bits that can be easily transmitted and then decompressed. MPEG is able to accomplish this level of compression rate by storing only the changes between sequential frames rather than each individual frame of video. MPEG provides a very efficient and scalable ratio of compression. With a ratio of 20:1 to more than 400:1, many manufacturers had moved towards using MPEG for remote viewing and storing video. Some of the MPEG standards include MPEG1, 2, 3, 4, 7 and 21.

H.264 – The advancement in compression technologies in the last few years has resulted in development and increased implementation of the H.264 compression. The H.264 also referred to as MPEG4 part 10 is the result of refinements made to the block-based encoding method well established with MPEG-4. H.264 which introduces smaller block sizes, greater flexibility and greater precision in motion vectors.

There are countless other compression technologies that have been developed for the purpose of transmitting video images from point A to point B. As hardware manufacturers improve their products, the software engineers will find new ways to make improvements in compression algorithm while increasing video quality at the recorder end.
Bitrate and Bandwidth

Since all digital images are created by a series of orthogonal pixels, each frame of video includes a certain number of horizontal or width (W) and vertical or height (H) pixels. Each frame of digital video is considered to have a W x H size. Pixels have only one property, their color. The color of a pixel is represented by a fixed amount of bits. The more bits the more subtle variations of colors we can reproduce. This is called the Color Depth (CD) of the video. For example, the properties of the video mentioned earlier, having a size of 640x480 with a color depth of 24 bits and a frame rate of 30 fps is displayed as:

Total number of pixels per frame = 640 (W) * 480 (H) = 307,200
Total bits per frame = 307,200 * 24 (CD) = 7,372,800 = 7.37Mbits
Bitrate (BR) = 7.37 * 30fps = 221.2Mbits/sec
Video size (VS) = 221.2Mbits/sec * 3600sec = 796,320Mbits / 8bits per Byte = 99,540Mbytes = 99.54GBytes / hour

The most important properties are Bitrate and video size. The formulas relating those two with all other properties are:

\[ BR = W \times H \times CD \times FPS \]
\[ VS = BR \times T = W \times H \times CD \times FPS \times T \]
(Units are: BR in bits/sec, W and H in pixels, CD in bits, VS in bits, T in seconds)

By its definition Bitrate is a measure of the rate of information content of the digital video stream. In the case of uncompressed video, Bitrate corresponds directly to the quality of the video. Bitrate is an important property when transmitting video because the transmission link must be capable of supporting that Bitrate. Bitrate is also important when dealing with the storage of video because, as shown above, the video size is proportional to the Bitrate and the duration. As mentioned before Bitrate of uncompressed video is too high for most practical applications and that is why video compression is extremely important for storing and transmitting a video signal. All compression methods compress video frames differently and at different levels. The level or the rate with which a video frame is compressed is known as Compression Factor (CF). Utilizing compression factor, the equation above will look like this:

\[ BR = W \times H \times (CD / CF) \times FPS \]

The value represented by (CD/CF) is considered as Average Bits Per Pixel (BPP). BPP is a measure of the efficiency of compression. A true-color video with no compression at all may have a BPP of 24 bits/pixel making it an incredibly large file to manage. The idea of transmitting uncompressed digital video from point A to point B is not only impractical, it is impossible with the available communication networks. Even Compressed video at high frame rates and quality require huge amount of available network resources. The amount of available or consumed communication resources on a network is known as Bandwidth. Understanding and Managing network bandwidth is very crucial when dealing with video transmission. Below are some of the common methods of communication between two points and their appropriate bandwidth.
Considering the uncompressed video example mentioned earlier, it requires nearly three times the Fast Ethernet network to transmit one second of the video from point A to point B in real-time. Of course, that will not be necessary thanks to video compression. However, even with compression, transmitting multiple camera images at various frame rates per camera still demands substantial bandwidth if any usable and practical outcome is desired at the remote site. Simple calculations using the equation above with compression factors available for each compression method, you can estimate the bandwidth required for transmitting the video from the DVR to a remote location with much expected results. However, you must keep in mind that there are other factors involved in the transmission that may be out of your control such as Internet or network traffic, number of points (Nodes) and the additional equipment the video data is travelling through before reaching its destination.

Although the entire digital video technology cannot be described within a short article, we hope that the information provided here is helpful in better understanding this ever changing technology and its basic components.