Analog vs. Digital Cameras

In their early development, electronic cameras were all analog – analog television cameras, analog surveillance cameras, and an analog image chain in medical fluoroscopy, to name just a few. The rise of affordable computer technology created the desire to transmit camera images directly to a computer. But frame grabbers for analog cameras, where the analog signal from a camera is digitized using electronic circuitry physically separated from the camera, were quite expensive at that point and still preserved some of the disadvantages of analog imaging technology that were dictated by the limits of the analog signal path. In time, pure digital-hardware-based image processing was developed for industrial applications. The hardware supported high velocity data transfer, but it was also very expensive. However with the advancement of digital technology, the spread of more advanced communication protocols, the marked reduction in the cost of PCs, and the development of standardized hardware and communication interfaces, the costs related to a digital solution dropped dramatically.

The first noteworthy step was the introduction of the IEEE1394 standard. Although IEEE 1394 devices quickly encountered application barriers due to their limited data transfer velocity, they are still a good choice for many less demanding applications. Another milestone in the progression of digital technology was Gigabit Ethernet. High data rates and the ability to provide both camera power and data transfer via a single standard cable (an ability known as Power over Ethernet or PoE) allow the creation of cost-effective solutions that are especially popular in machine vision and security applications. Basler has recognized the potential of GigE technology, and we constantly strive to make advances that will benefit users in the GigE camera marketplace. But before we say anything more about this, let's get back to the basics. What are the main differences between digital and analog cameras?

Basic Differences

An analog camera provides image information as continuous signal levels that are either displayed directly on a monitor or that are digitized outside of the camera in a second step using special hardware.

In a digital camera, the digitization of the image information is performed inside of the camera immediately after the image information is captured by a sensor. The physics of an imaging sensor dictate that image information is in an analog form. The transformation from an analog to a digital signal is performed inside of the digital camera using additional electronics that are not available in an analog camera.

- **Price** – Until now, if only the price of the camera was taken into account, analog cameras were cheaper than digital cameras in most cases. But if the costs required for the additional hardware necessary to display, to store, or even to digitize the analog image information are considered, the price advantage of an analog camera quickly melts away. Now that digital hardware is in large-scale production, e.g., standard PCs and digital cameras, the financial requirements are greatly reduced for many applications. While it is true that some high end digital solutions are still quite expensive, the performance of these high end systems cannot be matched by any analog camera.

  To further accelerate the trend from analog to digital, the price positioning of the new GigE cameras has been set to correspond to the prices of analog cameras. New camera products such as Basler's ace series now have a very reasonable starting price of 299 € and are much more attractive for applications where analog cameras have traditionally been used. They meet the cost demands of analog camera users while offering the technological advantages of a digital camera.

  In brief, the latest digital solutions are price competitive with analog products.

- **Reduced System Costs** – The overall electrical design complexity for the installation of a PoE camera is reduced because fewer cables must be used in the system. When the lower cable complexity is coupled with the automatic IP addressing schemes usually available, it means that a robust, multi-camera system is easier for a user to install and maintain. System costs can be minimized from the start, and future costs for maintenance and possible up-

grades can be considerably reduced. All told, the system becomes more robust, reliable, efficient, and easier to maintain.

In brief, digital PoE cameras are robust, reliable, easy to install, and easy to maintain. Therefore the costs are reduced.

- **Stability Over Time** - Analog cameras use circuits based on potentiometers, capacitors, and amplifiers to perform such functions as white balance, gain, black level, offset, and other functions critical to video performance. These components are subject to thermal and temporal drift. Digital cameras are calibrated and referenced in the digital domain. Once calibrated at the factory, the calibration and reference values are permanently stored in pages of ROM. These values remain constant.

  In brief, digital cameras have better stability over time and temperature.

- **Noise Immunity** – Analog cameras are usually based on a video signal with a 700 mV to 800 mV active range, from black to fully saturated white. Though the shielding of coaxial cabling does provide some protection, only a few mV of external noise is relevant to the overall signal level and can begin to affect the video signal.

  In contrast, digital signals are either voltage or current driven around a threshold value. Anything above the threshold is seen as a digital "high" and anything below the threshold a "low". External noise must reach a level capable of forcing the video signal above or below the threshold value before interfering with the video signal. This level of noise rejection is inherently hundreds or thousands of times greater than that of analog systems. Additionally, RS-644, Camera Link, and other digital standards use differential signaling methods that further increase noise immunity. Both analog and digital cameras may be high quality video sources, but in noisy environments, the images captured by a digital system will have the highest Signal-to-Noise ratio (SNR).

  In brief, digital cameras are more resistant to electromagnetic noise.

- **Higher Performance Video** – Today's customers, especially in the machine vision market, have ever-increasing demands for their applications. Speed and resolution have become the foundation of video performance. Cabling and capture technology limit analog cameras and capture systems to maximum pixel clock speeds of around 40 MHz. This ultimately limits the capability of the camera.

  Current digital standards allow for pixel clock speeds of 85 MHz and beyond. In addition, multiple taps allow for parallel data paths from the camera and increase the camera's capabilities even more. As video frame rates venture into the hundreds or even the thousands of frames per second and resolutions go to 2 MP, 4 MP, and beyond, only digital solutions offer the speed and bandwidth necessary to handle the video demands of the future. Cameras like the Basler ace acA2000-340km/kc (340 fps @ 2048 x 1088 pixels) would not even be possible with analog-only systems.

  In brief, digital cameras allow higher video performance than analog cameras.

- **Advanced Features** – At the heart of any digital camera is a microprocessor, FPGA, ASIC, or other processing device. In recent years, these devices have become not only smaller and more efficient but also more powerful. Besides simply operating the camera, manufacturers of digital cameras can use this power to provide advanced

  features such as color enhancement, on-the-fly subtraction of a reference image, custom Gamma or lookup tables, and more. For OEM customers, custom features can be added to their specifications, making their cameras even more cost-effective and efficient imaging devices. These types of features and performance are not possible in cameras that are strictly analog.

  In brief, the provision of advanced features is only possible on digital cameras.

- **Ease of Use** – Digital standards such as IEEE 1394 (FireWire) offer users unprecedented access to industrial cameras and high performance video. Apple and Windows PCs directly support industrial spec video (DCAM or IEDC). Since they are truly plug-and-play, users can plug industrial spec IEEE 1394 cameras into their systems and live video will immediately appear in a default viewer.

  The emergence of the GigE Vision standard means that a Gigabit Ethernet network can be exploited for camera applications. Gigabit Ethernet connections are now available as standard equipment on every PC.

  In brief, digital cameras are much easier to install, to configure, and to customize than analog cameras. Many software packages are available that support fast and efficient integration of digital cameras into an application.

- **Presence** – Many analog camera users stick to their existing solutions because they are already in place. Why should a solution be changed when it is in place and working? This is a reasonable point of view, as long as legacy hardware is still available. But when was the last time you saw a new VHS video recorder? (By the way, they were invented in the seventies.) In addition, a digital solution can save a lot of physical space, which can be used for other purposes.

  In brief, force of habit may cause some users to miss the opportunities presented by the latest digital technology.

- **Size** – Differences in the footprint size of analog and digital cameras were a problem in the past, but this problem was overcome with the new GigE camera generation.

  During the development of the newest GigE cameras, a reduction in size was one of the main objectives. In previous generations, miniaturization was a secondary goal because the addition of components for the GigE interface, their integration and harmonization, and the minimization of power consumption were already challenging

  enough. Now, GigE cameras are in a third generation and they have the typical footprint of analog cameras (29 x 29 mm). That is why current GigE cameras can readily replace analog cameras, USB cameras, and IEEE 1394a or b cameras.

  In brief, the latest digital cameras have the same footprint as analog cameras

- **Single Cable Solution** – With Power over Ethernet, cameras can be connected using only a single cable; the need for a separate power supply cable becomes obsolete. A single standard GigE cable can easily be used both to transmit power to the camera and to make a network connection. Because the network signals and the power supply voltage are simply superimposed on each other without disturbing the standard network cable wiring scheme, there is no loss in data bandwidth. Users no longer need specific, expensive cables for the power supply, and this can result in a considerable cost reduction for larger camera systems.

  In brief, digital PoE cameras can be connected with only a single cable.

This overview lists most of the characteristics, advantages, and disadvantages of both technologies. Digital cameras can be considered as beneficial compared to analog cameras, even though analog solutions have sometimes had an advantage in price. New developments, especially the latest generation of GigE digital cameras, weakens even this last argument for analog cameras.

Benefits at a Glance

- The latest digital cameras are price competitive with analog products.
- Digital PoE cameras are robust, reliable, easy to install, and easy to maintain. Therefore costs are reduced.
- Digital cameras have better stability over time and temperature.
- Digital cameras are more resistant to electromagnetic noise.
- Digital cameras allow higher video performance than analog cameras.
- The provision of advanced features is only possible on digital cameras.
- Digital cameras are much easier to install, to configure, and to customize than analog cameras. Many software packages are available that support fast and efficient integration of digital cameras into an application.
- The latest digital cameras have the same 29 x 29 mm foot print as analog cameras.
- Digital cameras with Power over Ethernet can be connected with only a single cable.

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