WHITE PAPER

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How Machine Vision Cameras Help Medicine

An Analysis Focused on Color Fidelity and CCD/CMOS Sensors

Cameras have been playing an increasingly important role in medicine for many years now. Regardless of whether you‘re looking at medical devices, laboratory automation or the operating room, in almost every field there are a multitude of everyday applications where cameras are a significant component. This is especially true for microscopy, ophthalmology, pathology, endoscopy, lab automation and biomedical research.

The first part of this White Paper will review the major characteristics of digital cameras to highlight the benefits of machine vision (MV) for medical applications. The topics of color calculation and the concept of color fidelity will then be explored. Finally, the trend away from CCD toward CMOS sensors will be discussed, including a presentation of both sensor types and their respective advantages and disadvantages.

Contents:

1. Selection Criteria for Cameras in Medical Applications

While the rapid development of new sensor and interface technologies has been largely consumer driven, it has also had an impact on the development of medical products featuring cameras. Selecting the right camera for a medical application is an increasingly difficult task, given the enormous range of available sensors and interfaces. In many cases the decision must account for a variety of factors, some application specific, others general. Key criteria here include (1) size and form factor, (2) camera environment, (3) camera sensor, (4) interface, (5) lens, (6) expected service life of the platform and (7) customization options. While (1) - (5) are product-specific requirements, points (6) and (7) differ from camera maker to camera maker. This paper will sketch out the basic expectations for cameras for medical applications and highlight how machine vision cameras are designed to offer decisive benefits over consumer-grade cameras or proprietary products with pre-integrated sensors.

Size and Form Factor
Size and form factor are one deciding criterion for selecting a camera. If a camera is used as an external image sensor, such as to monitor an operation or as a microscopy camera, then the device must be mounted in a stable housing. When the camera is integrated directly into the device, then space is a much greater factor and greater emphasis is placed on compactness and size. The interface and cable connectors play a role here as well. Lateral USB ports require more space for cabling, while LVDS-based interfaces with ultra-flexible ribbon cables can be mounted even in highly limited spaces. Machine vision cameras are designed to be robust enough for industrial environments. Unlike consumer cameras, factors such as sensor spacing, camera deformation and the related impact on Field of View (FOV) are calculated into its design. This is necessary to ensure a high degree of stability and reproducibility of the image data.

Camera Environment
Considerations of the camera environment and deployment scenarios are other critical points in the decision-making process. Cameras are frequently confronted with variable lighting conditions. Instead of using two cameras, machine vision cameras work with software to adjust the camera settings to different ambient conditions. For typical MV camera software, this means controls over features such as exposure time, trigger and white balancing.

Camera Sensor
The optical sensor is one of the most crucial components. Depending on what kind of object is being inspected, an integrated sensor must be able to capture full-resolution

images from a minimum threshold distance. When cameras are used for diagnostics, high resolutions of up to 20 MP can be expected for high-sensitivity sensors.

The frame rate is also application-specific. If live images allowing for user interaction (such as for microscopy cameras) are needed, then sensors with 25-30 fps (frames per second) are typically needed for fluid image reproduction. Conversely, frame rates are not at all critical for the examination and analysis of fixed samples.

However, other decision criteria are important, such as sensor type. For most applications, (including the refractometer for ophthalmology) a monochrome sensor is the right choice. In other applications, such as when recording images of the eyeground (retina), the color of the object of investigation does matter to the analytical process. This is especially prevalent in diagnostic applications (such as for ophthalmology, pathology and dermatology). Correct color reproduction by the camera is another important criterion, one that will be addressed in detail in this White Paper.

Applications that work under low-light conditions (such as fluorescence) require special sensors with good quantum efficiency, low dark noise and read-out noise. High Signal to noise ratio (SNR) and pixels with large light-sensitive surfaces are additional decision factors for low-light applications.

Manufacturers of machine vision cameras generally offer a broad spectrum of sensors for their cameras, and in some cases identical sensors are designed to work with different interfaces. This eases the development process significantly, as off-the-shelf cameras can be used instead of having to develop a unit specifically for the application — important factors in keeping development costs and Time-to-Market (TTM) short and efficient.

Another plus point in comparison with cameras from the consumer field is image quality. Machine vision cameras have a direct on-board processing unit to handle preprocessing of the image. This technology has been perfected over the years and can handle CPU-intensive operations such as debayering, denoising and correctional algorithms. In best-case scenarios, the computational units use an FPGA (Field Programmable Gate Array) processing units to forward image data without delay via their interface.

One major plus point for MV cameras is the transparency of the parameters. While sensor read-out for cameras in the consumer field typically involves a black box process with a great deal of processing, developers of MV cameras have complete control over the camera settings and acqusition settings.

One other extremely important point: machine vision camera sensors are designed for 24-hour operation. While standard cameras may begin malfunctioning after just a few hours of continuous use — with image flaws and lost frames as the most typical phenomena — MV camera sensors can operate for years uninterrupted without limitation.

Interface

Gigabit Ethernet (GigE) is the most popular interface for machine vision cameras. GigE technology is also a favorite in medical applications because it is compatible with long cable lengths and standard network architectures. In recent years the simple plug-and-play functionality of USB3 has also gained in popularity. Manufacturers for the machine vision industry have developed standards specifically designed for the transmission of image data across over GigE and USB3 interfaces: GigE Vision and USB3 Vision. These protocols are significantly leaner, more stable and can quickly transfer streams of image data.

For smaller, portable devices, bandwidth is not just a key aspect in selecting an interface, but also for the image processing environment. In stereo applications, for example, LVDS-based interfaces are preferable. These can be integrated directly into a computational unit (such as an FPGA) on the customer's processor board to provide ultra-quick resolution of specific computational tasks — without increasing CPU load. Ribbon cables are also used with LVDS-based interfaces. These Flat Flex Cables are extremely flexible and are perfect for installing devices into tight spaces.

Lens

Once the camera, illumination, processing unit and algorithmic specifications have been determined, the next step is typically to classify the requirements for the lens. It can take years to produce a custom lens — making it all the more important that the selection of a lens occurs early in the development process. Several manufacturers of MV cameras offer matching lenses and corresponding cables. This "one-stop-shopping" saves time and crucial development resources, while also reducing the risk of supplier problems.

Long-term availability

The expected service life of a platform is another important aspect in choosing a manufacturer's camera. For applications in the fields of surgery, ophthalmology and medical diagnostics in particular, the long, difficult certification processes (ISO, FDA) frequently result product cycles that can last up to ten years. This makes it all the more important that the camera maker organizes a network of suppliers to ensure that the products will be available for the long term. This criterion is in fact so crucial that manufacturers of medical products typically skip over technical innovations in favor of products that they are confident will be available for an extended period.

Customization Options

Machine vision camera makers are accustomed to adapting their cameras to customer needs. This flexibility is of enormous importance in the medical field in particular. If a product is certified as a medical product, for example, then the firmware must be frozen for that customer at that stage of development, with new cameras delivered to the customer using that firmware. In many cases cameras must also fit into standardized medical housings, which involve customer-specific adjustments to materials, labels and colors.

Summary

Machine vision cameras and makers are thus outstandingly well suited for the medical market:

1. Long-lived cameras: stable housing, more precise placements of the sensor, good built quality

2. Stable, updated software with features to adapt the camera to various light/application scenarios — with high transparency in the utilized methods (no black box approach as seen in consumer-grade camera modules)

3. Broad selection of sensor and interface technologies, together with good support, ensure quick and efficient integration and short Time-to-Market

4. Machine vision cameras deliver accurate, durable and reproducible images with the object's real colors; consumer-grade cameras rely on algorithms with high color fidelity to make the image look aesthetic

5. CMOS sensors have become an affordable alternative to CCD sensors

6. Machine Vision cameras have GigE Vision and USB3 Vision interfaces specialized for image transfer

7. New interface technologies such as LVDS allow vision systems to be installed in the tightest of spaces (such as portable devices, stereo vision)

8. One-stop-shopping: camera, lens and cable from one source to minimize supplier problems

9. Manufacturers of Machine Vision cameras can offer long-lived software and hardware platforms over many years

10. Customer-specific customizations (colors, labels, materials, etc.) can be implemented as an add-on service

2. Color Fidelity in Medical-related Camera Applications

Color fidelity is of absolutely central importance in several rapidly growing medical diagnostics fields, including digital pathology, ophthalmology, hematology and microscopy. One example to illustrate the importance of high color fidelity is digital pathology. Digital pathology is a helpful tool for images of specimens to be transferred between two different labs. It allows for cheaper, more efficient and robust diagnoses to be issued, as experts are no longer limited by physical distance in terms of specimens that they can examine. Software helps them view and comment on the digitized specimens. Once digitized, suspicious areas within the sample can also be submitted to analytical algorithms. These so-called computer-assisted diagnostics are based on pattern recognition algorithms such as neural networks and have made massive improvements in recent years; their importance is only expected to grow. This process makes diagnoses more reliable while also saving time and money, since the specimens can be pre-reviewed. Experienced pathologists view the coloration of specific structures within the specimen as a powerful indicator for their diagnostic analyses, so cameras must satisfy a strict set of expectations to ensure that the digital version of the physical specimen properly reflects its detail and color tone.

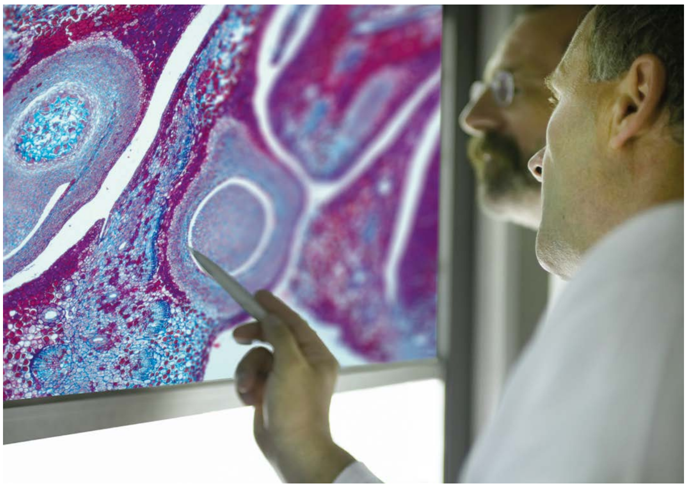

Fig.1: Digital Pathology: Once the specimen has been digitized, experts can identify pathogenic structures and apply pattern recognition algorithms.

Another application where the diagnoses strongly relies on color fidelity, is digital dermatoscopy. During digital dermatoscopy, potentially malignant skin structures are recorded by a camera. While traditional optical dermatoscopes do allow for assessment of skin sections that are suspected of cancer, they do not offer standardized documentation or quantified observation over time. Each digital dermatoscopic examination photographs suspicious skin changes using a camera. By performing this across various points in time, the development of the pigment can be recorded digitally. Software records the images and makes them visible to the dermatologist. Various criteria such as radius and color provide the dermatologist with key information to form a diagnosis. Color fidelity is thus an important aspect of the diagnostic process and shapes several of the requirements for the camera. For digital dermatoscopy in particular this is not of trivial interest, as the color must be accurately reproduced regardless of the illumination type and luminous color.

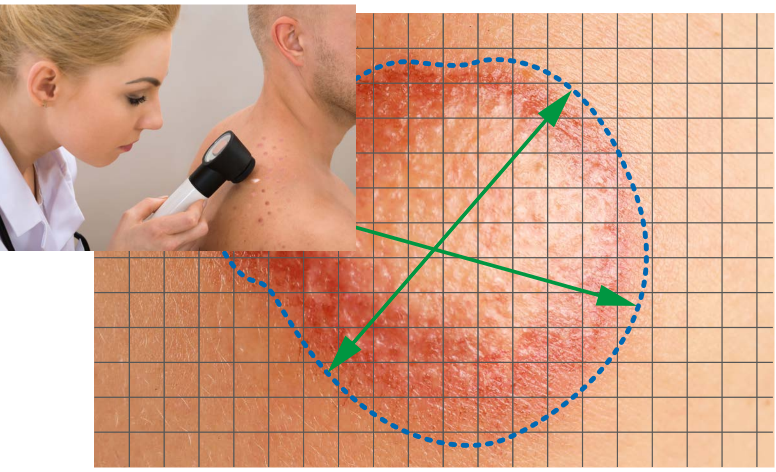

Fig. 2: Digital dermatoscopy: Potentially pathogenic structures on the skin's surface are recorded at various points in time using a digital dermatoscope and then analyzed using software.

2.1 From Object to Measurement Value: How Digital Cameras Depict Color

The aforementioned applications provide good examples of how cameras serve as tools for documentation, visual support and measurement, and just how strict the requirements for color fidelity by digital cameras really are for medical/technical applications. To describe the process of color reproduction, one must first examine how object color and an image's intensity values are determined: The path runs from the object through the lens to a sensor, which is then transformed by the camera into a color value.

During image acquisition, the light reflected from the object initially moves through a lens onto the camera's sensor. All three components are of decisive importance: The better the illumination of the object, the greater the precision at which the sensor can capture the color intensity. Because the reflected light is projected via a lens onto the sensor, this is also of importance.

The sensor is comprised of many individual pixels that can record the incoming photons of light and, depending on their volume, report their findings via an electrical signal of varying intensity. The individual pixels can thus be understood as "buckets" capturing the incoming photons. To differentiate between the number of photons and their spectral association (wavelength), color sensors feature a filter layer known as the Bayer pattern or Bayer matrix *(Fig. 3)* that allows photons of a specific wavelength to pass through (red, green or blue) even as photons of the other wavelengths are blocked *(Fig. 4)*. The design of the Bayer pattern can very between different sensor models, but generally speaking consists of three types of filters: 50 % green, 25 % red and 25 % blue.

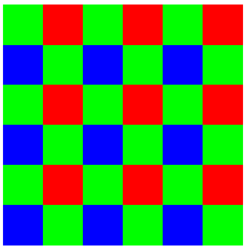

Fig. 3: Bayer pattern with different filters above a sensor's pixels. Each color pixel is comprised of 4 base pixels (blue, 2x green, red).

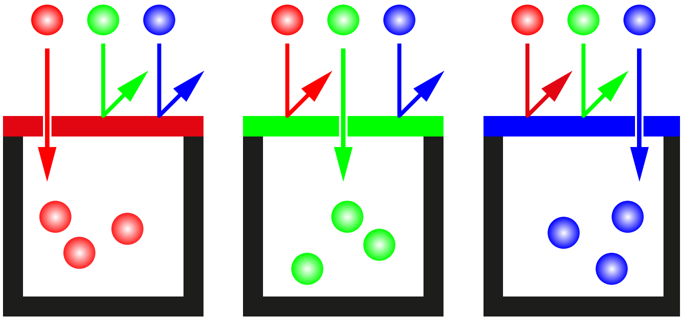

Fig. 4: The pixels allow only light for a specific wavelength — red, green or blue — to pass through. Photons from other wavelengths are blocked.

2.2 Calculating the RGB Value

During the next step, the intensity values for the individual color pixels are used to calculate the color values. The goal is to interpolate the intensity values of the Bayer pattern (for example 8 bits per pixel) into RGB information (24 bits per pixel – 8 red, 8 green, 8 blue). This process is known as debayering and involves an interpolation of the missing color values. Debayering is computation intensive intensive. Modern cameras, including Basler models, handle this chore internally, using their own built-in FPGAs. For the user, this means less computational load; for embedded applications in particular, where memory and computational resources are highly limited, this is of major importance. By using an FPGA, latency times from calculation are also kept to a minimum.

Any variation in color reproduction can cause major problems in color medical images. The standardized sRGB color space was developed to help deal with variances between different cameras or sensors. Medicine in particular, which prioritizes standardized documentation, relies on sRGB as a pillar of standardized color reproduction. sRGB ensures that image data with identical sRGB values will look the same on color-calibrated sRGB monitors the world over.

Two corrective algorithms are required within the camera to transform camera-specific RGB values into standardized sRGB values: color calibration and gamma correction.

2.3 Color Calibration

As described above, the color values created by the camera rely in large part on factors such as illumination, lenses, sensor and interpolation (debayering). Before medical diagnostics can rely on the calculated color values, a series of steps are required to ensure this adjustment of the colors to the real object: a process known as color calibration. In modern camera systems, color calibration is comprised of three sub-steps: a so-called matrix correction and a correction using a six-axis operator. Once these are completed, a so-called gamma correction is performed, although this is not in and of itself a color calibration step.

The calibration process uses three ColorCheckers *(Fig. 5, right)*. It is a chessboard-style card with 24 colors and 6 gradations of gray depicted as squares next to one another. When viewed under certain defined lighting, the sRGB values for the individual fields are a known factor *(Fig. 5, left)*, allowing the ColorChecker to serve as a reference benchmark for the colors as detected by the camera. The color value for the camera is measured based on a specific field, providing the sRGB value that can then be used to compare with the actual, known value for the color field. The length of the vector between the measured and known point in the color space is described as ΔE *(see Fig. 6)*, and is referred to as the color error. A ΔE of 1 is described as a *just noticeable difference* (JND). A ΔE of greater than 1 is perceived as different color. The goal of the calibration process that then follows is to reduce the color error ΔE as far as possible. In the past, there were a variety of methods for calculating color error ΔE. During the 70s, ΔE_{ab} as described above was used to measure the Euclidean vector distance; more recent definitions such as ΔE_{94} and ΔE_{00} are used to account more precisely for human perception in the distance between the points.

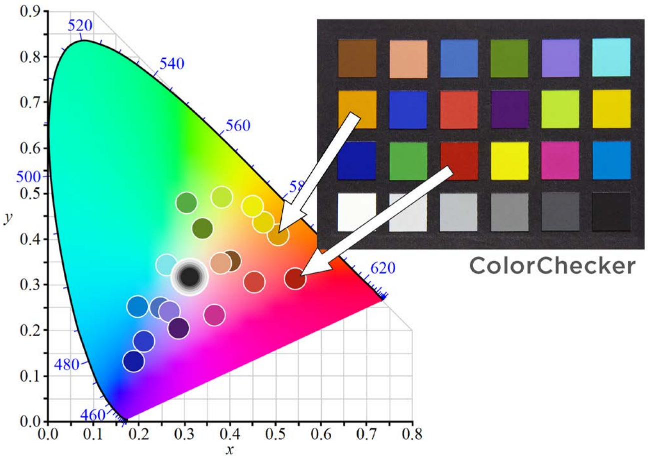

*Fig. 5: ColorChecker with 24 colors and 6 gradations of gray. sRGB value of the ColorChecker in the L*a*b* color space (or one level of it).*

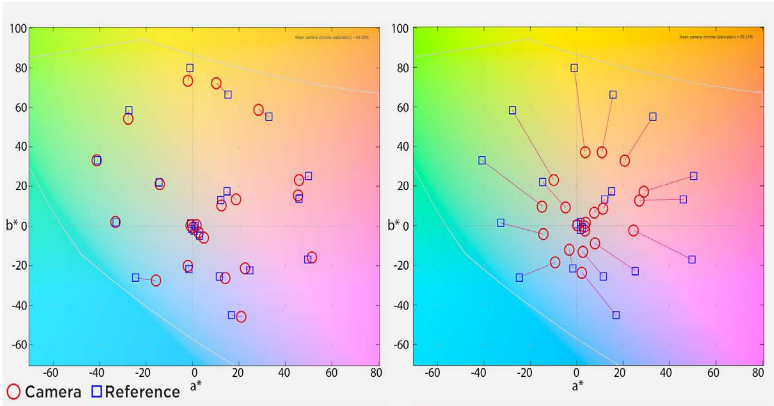

Fig. 6: The length of the vector between the measured point (round point, camera) and the measured point (square, reference) is described as the color error ΔE. Thanks to the color calibration, color error is kept to a minimum.

2.3.1 White Balancing

White balancing is used to adjust the camera to the color temperature of the light used to illuminate the object of the photo. The gray fields on the ColorChecker are used to achieve this. The human eye performs its own version of white balancing, known as chromatic adaptation. It prevents humans from subjectively perceiving changes to the color temperature in ambient light. A white sheet of paper looks relatively similar in both daylight and artificial lighting.

White balancing can be conducted in a variety of ways. Probably the simplest method is activating the user, with instructions to use a viewer to select a white area. Many applications undertake the white balancing automatically, however. Any of several different procedures can be used for this, such as the highly simple *Grey World* procedure. It presumes that in a normal photo the average of all colors is gray. If the difference between gray and the calculated color average is determined and then multiplied by the color channels, then the white surfaces should total R=G=B.

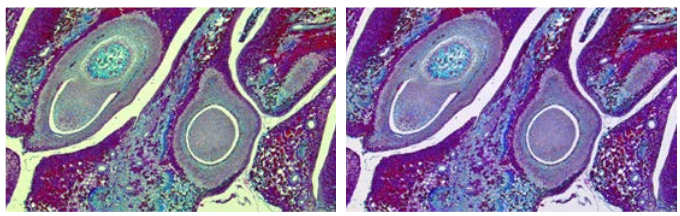

Fig. 7: Effect of white balancing Live image of a Basler pulse puA2500 microscopy camera
Left: Prior to white balancing Right: After automatic white balancing.

2.3.2 Matrix Correction

Matrix correction is used to adjust the spectral sensitivity of the color pixels in the sensor to those of the human eye receptors. Because the RGB color universe is comprised of red, green and blue, this is multiplied out into a 3x3 color matrix that approximates the correct color tone. The result of the matrix correction is then used to transform the camera-specific RGB value into the standardized sRGB value.

2.3.3 Hue, Saturation

When developing vision systems for medicine, the images are expected not just to have as little color error as possible, but also in many cases to be aesthetically attractive. In particular, cameras being employed not just for measurements but for photographic documentation as well — as is the case for example with macroscopic observations of cellular structures — often leave users desiring attractively colored images. Functions such as hue and saturation are important in this regard.

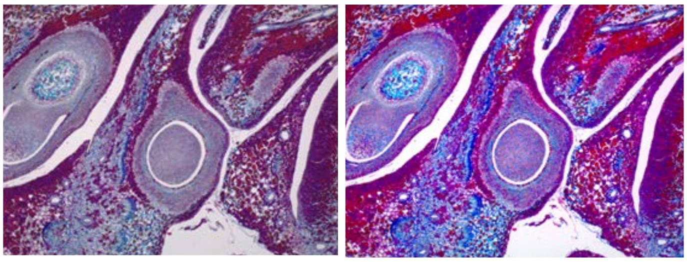

Fig. 8: Increase to saturation during a live recording of cellular structures with a microscopy camera (Basler pulse puA2500).

Within the color space, an increase to the saturation causes a relocation of the color points to the outer edge of the space *(see Fig. 9, right)*. A change to the hue, by contrast, causes the color pixels to rotate *(see Fig. 9, left)* It's important to remember that saturation and hue are global operations. Any changes made using those functions will affect all colors to an equal degree.

2.3.4 Six-Axis Operator

Unlike hue and saturation, the six-axis operator is not a global operation. This now makes it possible to process individual colors within the color space — without affecting other colors.

For some applications, including eyeground photography, users are trained to look for retina color impressions, or else have learned to do so through years of practical experience. Six-axis operators allow for color representations to be adjusted to the user's own preferences. Among other effects, this means that when new devices are being developed, even when camera components need to be replaced, the impression from the image remains the same.

Beyond this, the six-axis operator also makes it possible to enhance the differences between two colors (such as for example two highly similar red tones). In this example, light and dark red can be recast as yellow and magenta.

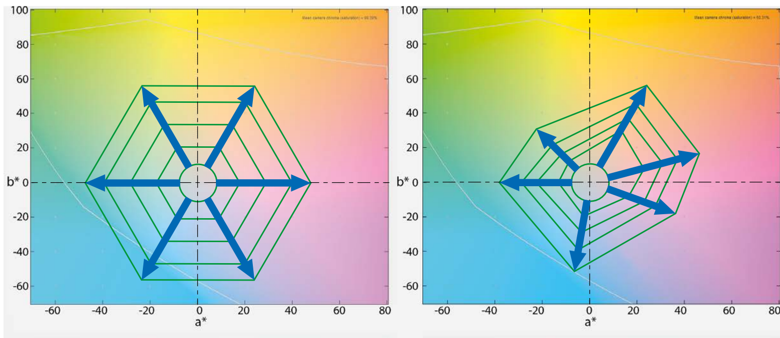

*Fig. 9: Visualization of the operations on a level of the L*a*b color space. Left: While hue and saturation are global operations affecting the points in the color space (meaning any change to saturation impacts all colored points equally), the six-axis operator (right) allows for individual colors of the color space to be transformed to a different color — without affecting any other colors that are present.*

2.4 Gamma Correction

Unlike the human eye, camera sensors perceive brightness as linear values. In other words, twice the number of photons represent twice the measured intensity value. For evolutionary reasons, the human eye perceives differentiations in brightness in non-linear ways. Differences in the brightness of dark areas are perceived more strongly than in light areas. Gamma correction must thus be performed before an acquired image can be properly rendered on a device. It corresponds to the exponentiation of the intensity values based on a curve that enlarges the brightness differences in dark areas and reduces them for light areas. The objective is to re-attain linearity for the gray values on the monitor. Because the image is confronted with convex non-linearity along the transmission path, the image must be multiplied in advance for a concave non-linearity to compensate for the effect *(see Fig. 10)*.

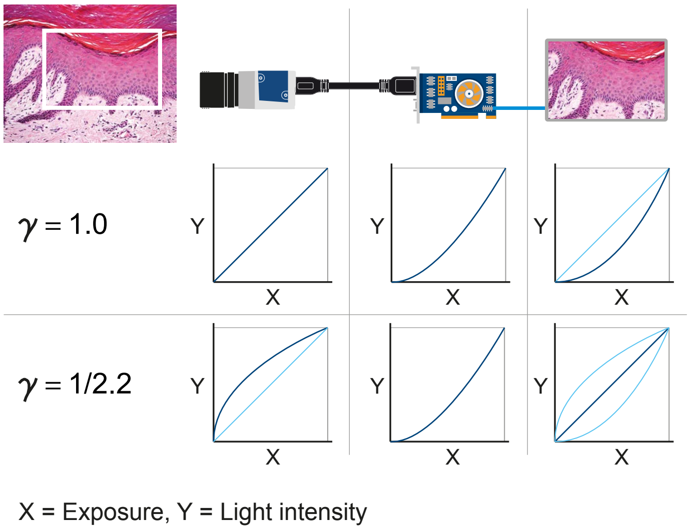

Fig. 10: Visualization of gamma correction. The captured image must be run through gamma correction to compensate for the inverse gamma curve during transmission and allow for the image to ultimately be shown in a linear progression on the monitor.

2.5 Practical Color Calibration

The latest generation of cameras feature pre-defined color calibrations (white balancing, matrix correction and six-axis operator). These settings can be pre-calibrated for specific scenarios (Daylight 5000 Kelvin, Daylight 6500 K and Tungsten 2500 K), allowing the cameras to be used out-of-the-box in these situations. If the user wants to conduct a color calibration process specifically tailored for his or her vision system and its special lighting, then only a few camera makers, Basler being one of them, provide the necessary software.

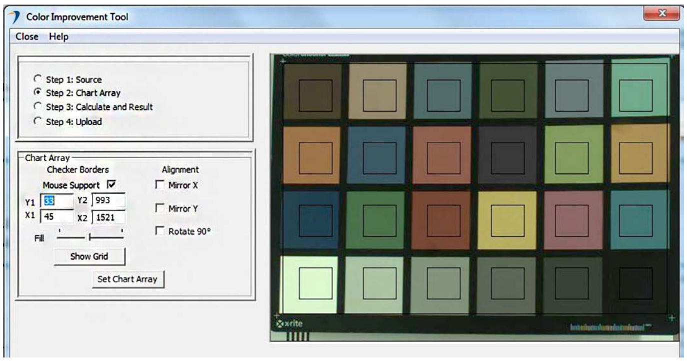

Fig. 11: Color Improvement Tool. The software framework receives as input an uncalibrated camera image depicting the ColorChecker. The color error is calculated and the parameters for white balancing, matrix correction and six-axis operators are then optimized to reduce error. The parameters can then be transmitted directly to the camera.

Industrial cameras without color correction typically demonstrate color error measuring from 10 to 20. Thanks to color calibration, modern (Basler) cameras total ΔE of 3 to 4, which is sufficient for the high standards required by medicine.

Summary of Color Fidelity:

- The key factors for color fidelity are lighting, sensor and color calibration.
- Pre-processing such as debayering, white balancing, gamma correction, matrix correction and six-axis operator can minimize color errors or adjust colors to previous color profiles (such as for new products that are replacing existing vision systems).
- The measurements determine color error a.k.a. ΔE, with ΔE 3 - 4 considered very good.
- Pre-calibration to defined light temperatures reduces the integration costs for standard camera environments.
- Calibration of the color matrix can also be adjusted by the customer for the specific system.
- Debayering using FPGA saves computational resources on the host side.

3. Switching from CCD to CMOS Sensor Technology

More Info!

There are two types of image sensors for industrial cameras on the market: CCD and CMOS sensors. Yet the trend has long been toward CMOS sensor technology as the wave of the future. This should come as no surprise, as CMOS sensors have made major strides in recent years in two important parameters for area and line scan cameras, namely frame rates and noise levels. Beyond this, CMOS is cheaper, which allows for additional savings beyond the already-generally-falling system prices.

3.1 What is the Difference Between the Two Sensor Technologies?

CCD (charge coupled device) and CMOS (complementary metal oxide semiconductor) image sensors are currently on the market. Their task is to transform light (photons) into electrical signals (electrons). This information is, however, transmitted by both sensor types using different ways and means and the design of each is also fundamentally different.

3.2 CCD Sensor Design

In CCD sensors the charges of the light sensitive pixels are shifted and converted into signals. The charges of the pixels, which are created by exposure to a semiconductor, are transported to a central analog/digital converter with the support of many very small shifting operations (vertical and horizontal shift registers), similar to that of a "bucket chain". The transfer of the charges is forced with the support of electrical fields, which are created by electrodes in the sensors.

The transfer of the charge in the CCD sensor requires a great deal of time. This is particularly a disadvantage with high resolution sensors where the charge must be fed into the central amplifier by many shifting operations based on the large number of pixels. This significantly limits the maximum frame rate.

3.3 CMOS Sensor Design

In the CMOS sensors, a capacitor as a charge storage is put in parallel to each individual pixel. This capacitor is charged with the exposure of each pixel by its photoelectric current. The voltage created in the capacitor is proportional to the brightness and the exposure time. Unlike CCD sensors, the electrons captured in the capacitors by the exposure of the sensor to light are not shifted to a single output amplifier but are transformed into a measurable voltage directly at the source by means of each pixel's own associated electronic circuit. This voltage can then be made available to the analog signal processor. By using additional electronic circuits, each pixel can be addressed, without the charge having to be shifted as with CCDs. This results in the image information being able to be selected much more quickly than with CCD sensors, and artifacts due to overexposure such as, for example, blooming and smearing, occur far less or not at all. The disadvantage is that the additional space required for each pixel's electronic circuit is not provided as a light sensitive area. The portion of the light sensitive area on the sensor surface (defined by the fullness factor) is then smaller than that of the CCD sensor. Theoretically for this reason fewer photons for the image information can be collected. There are methods, however, for lessening this disadvantage.

CMOS sensors have a higher full well or saturation capacity, which defines the maximum number of electrons per pixel. In many cases this is artificially bound to a lower saturation threshold.

So while a CCD sensor offers a better sensitivity threshold, the CMOS sensor more then makes up for it in its dynamic performance through its superior saturation capacity. As such, CMOS and CCD sensors perform at almost equal dynamics levels.

While CMOS sensors represent newer technology than CCD sensors, they are at this point themselves technologically mature products and for many applications actually represent the better alternative.

Differing read-out behavior for CCD and CMOS pixels:

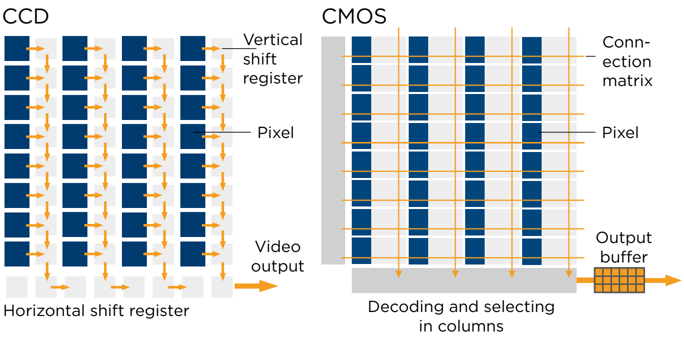

Fig. 12: Design of a CCD sensor (left) and a CMOS sensor (right). The charge is shifted further pixel by pixel to the CCD sensor. In the CMOS sensor, on the other hand, the charge of each pixel is directly converted to a voltage and read, which makes the CMOS sensor noticeably faster.

3.4 Benefits of CMOS Technology for Medical and Life Science Applications

As mentioned above, CMOS sensors have undergone significant upgrades in recent years, in many cases surpassing CCD sensors. Their high speeds (frame rate) and resolution (number of pixels), their low power consumption and, most recently, their improved noise characteristics and quantum efficiency have opened them up to applications previously reserved for CCD sensors.

The improvements to CMOS technology and the strong price/performance ratio in these sensors make CMOS sensors increasingly attractive for Medical and Life Science applications.

CMOS already has many advantages today:

- High speeds (frame rates)

  Thanks to their architecture, CMOS sensors allow for significantly higher frame rates. Combined with improved sensitivity and the latest global shutter technology from CMOSIS, Sony and ON Semiconductor, it's now possible to capture a very rapid sequence of images. This in turn increases performance in your applications — such as more parts inspected per second.

  - Seamless screening of microscopy samples
  - Rapid focusing for lab automation applications

- High resolution (number of pixels)

  Because of their architecture, CMOS sensors can deliver very high frame rates even at very high resolutions, which is why high-resolution sensors are primarily produced based around this technology.

  - Sufficient resolution reserves for automated specimen scanning
  - High resolutions are increasingly in demand based on the megapixel trends for microscopy

- Strong dynamic range

  The full well or saturation capacity is the maximum number of electrons per pixel. The ratio of full well capacity to sensitivity threshold represents the dynamic range the sensor can cover. So while a CCD sensor offers a better sensitivity threshold, the CMOS sensor more than makes up for it in its dynamic range through its superior saturation capacity. As such, CMOS and CCD sensors perform at almost equal dynamics levels. The Sony IMX174 sensor is a good example of a CMOS sensor that is superior in its dynamic range compared with all comparable CCD sensors.

  - Strong reproduction performance on microscopy cameras

- Low power consumption

  - Low heat production and power consumption, ideal for small or mobile medical devices
  - Data connections such as USB 3.0 can also be used to provide the overall camera with power; simplifies the system setup and thus cuts costs

- Improved noise behavior
  - The lower power consumption through CMOS sensors produces less heat, causing significantly less signal noise. Rule of thumb: every 8°C rise in temperature doubles the signal noise.
- Improved quantum efficiency

  Several years ago one might reasonably have said that CCD sensors were the better choice in low-light situations, while CMOS sensors were better in brightly lit situations. The image quality for CMOS sensors has improved so drastically, however, that they are now well suited for low-light situations as well.

  - Suitable for fluorescent applications
- Good price/performance ratio
  - Cuts costs for medical devices and systems

Thanks to the key properties of today's CMOS technology, this sensor technology seems destined to hold the upper hand for the long term.

Authors

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Since 2016, Peter Behringer has served as product market manager with responsibility for Basler's embedded cameras in the Medical and Life Sciences market.

Prior to joining Basler he earned a Master of Science in Medical Engineering at the University of Lübeck. While at university, he interned at well-known institutions including Charité Berlin hospital and the Surgical Planning Laboratory and Harvard Medical School.

Peter Behringer has published numerous scientific studies with a focus on image processing for medicine.

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22926 Ahrensburg
Germany

Basler AG

Basler is a leading manufacturer of high-quality digital cameras for applications in manufacturing, medicine, traffic and retail. Product development is led by the demands of industry. The cameras offer simple integration, compact sizes, excellent image quality, and an outstanding price/performance ratio. Basler has more than 25 years of experience in image processing. The company is home to more than 500 employees at its headquarters in Ahrensburg, Germany and its subsidiaries and sales offices in Europe, Asia and the USA.

Denis Dettmer

Denis Dettmer is a product manager at Basler AG. He had previously worked in Sales and Marketing for a manufacturer of banking automation and POS systems and as a product manager for self-service systems at a large German banking association. His career also included the position as a certified requirements engineer and project manager for an IT outsourcing company.

In his current position, he opens up his understanding of processes and his market expertise to Basler customers around the globe as a resource for information and advice related to board level cameras for the Medical and Life Sciences fields.

Within the company, Denis in his role as product market manager brings customer and technical requirements in terms of board level cameras with USB-interface into harmony with what is feasible at the product management level. This includes responsibility for short-term and future camera development for the vertical Medical and Life Sciences market.

Contact

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