White Paper

STELLAR: Redefining Possibilities in Low Light Imaging

Abstract

Surveillance at low light levels is plagued by inadequate photons that make it challenging to capture color images with good image quality. The poor image quality often manifests itself as noise that makes it hard to resolve fine details of a low-light scene. Dim regions of a low-light scene may also be completely blacked out due to limited image sensor sensitivity. In this document, we explain how image quality in such challenging low-light scenes can be enhanced by carefully designing and controlling different camera components such as lens, IR cut filter, sensor, and video processor.

STELLAR: Redefining Possibilities in Low Light Imaging

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Introduction

Surveillance technology has come a long way since the days of analog CCTV cameras storing VGA resolution video in a DVR. Modern security cameras have leveraged advances in image sensors, image processing, video compression, network bandwidth, storage, and video management software to offer extremely high resolution video at fast frame rates. In doing so, these modern cameras have provided improved security and other value-added services to their end users.

Security cameras have the constant need to adapt to their scene in order to be able to stream high quality video with varying lighting conditions. Consider a camera in an open parking lot for example. Between sunrise, midday, sunset, and nighttime, the camera is subjected to a wide range of illumination conditions that it needs to cope with. The range of illumination levels a camera can handle well is related to the design and control of a variety of individual components in a camera. A haphazard camera design fails to provide desirable image quality, since many of the control parameters available to a camera designer affect image quality in more than one way. For example, boosting a particular parameter may seem to improve light sensitivity but may also degrade resolution. This is why a good understanding of the interplay of different aspects of camera design is crucial for developing security cameras that will excel in their day-to-day challenges in the field.

With a careful design and control of camera components, Arecont Vision has developed camera technology that has the ability to generate high quality color video at extremely challenging low light conditions.

Camera Components Affecting Low-Light Performance

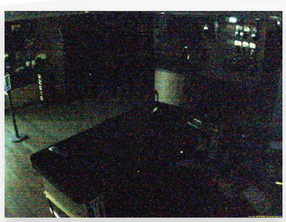
The four main components that affect imaging performance under low-light conditions are 1) Lens, 2) Infrared-cut filter, 3) Sensor, and 4) Processor

Lens

The lens of a camera determines the amount of light collected from a scene. The key parameter that quantifies

Figure 1: Low Light Problems

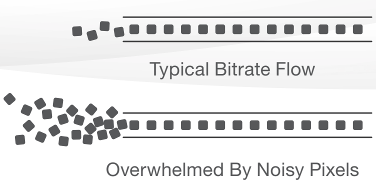
Video Appears Dark



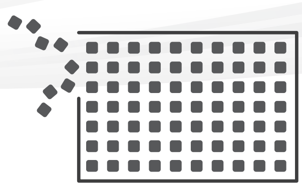
Video Corrupted with Noise

Increased Motion Blur

Color Information Lost in Night Mode



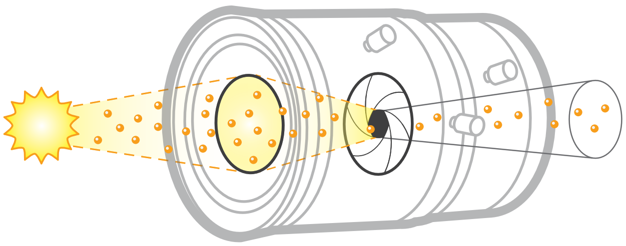
High Bitrates Overwhelm Resources



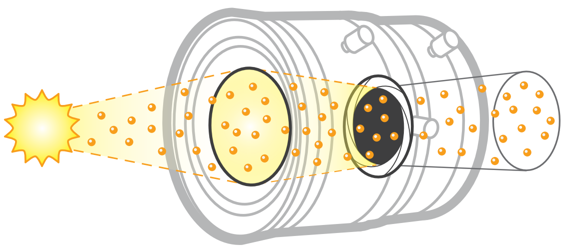
High Storage Requirements Also Overwhelm Resources

Low light surveillance is extremely challenging because only very few photons fall on camera pixels.

Figure 2-1: Effects of F/# on Light Collection



High F-Number
For bright sun-lit environments, an iris set to be not fully open is preferable.



Low F-Number
For a dark environments, a wide open iris and a shorter focal length collects more light.

the light-collection ability of a lens is the F/# (F-number). The F-number of a lens is the ratio of its focal length to the diameter of its aperture. As the F/# is reduced, the amount of light collected by the lens is increased. In lenses with variable focal length and adjustable iris, the F# can be decreased by increasing the diameter of the aperture, or by decreasing the focal length of the lens, or by a combination of both. For maximum light collection, a lens needs to be tuned so that its aperture is wide open and its focal length is as small as allowed by the lens.

However, one must be careful because decreasing the F# could affect a few other aspects of imaging that are unrelated to light collection. First, decreasing the F# by reducing focal length increases the field of view of the camera, which may or may not be desirable depending on the scene. Note that an increase in field of view also comes at the price of reduced pixels per foot (PPF). Decreasing the F# reduces a camera's depth of field (DoF), which refers to the range of distances that are in focus. An object located outside the DoF would appear blurred. The extent of blurring depends on how far outside the depth of field the object is located. It is therefore important to make sure that the DoF matches or exceeds the depth range of the scene to be secured.

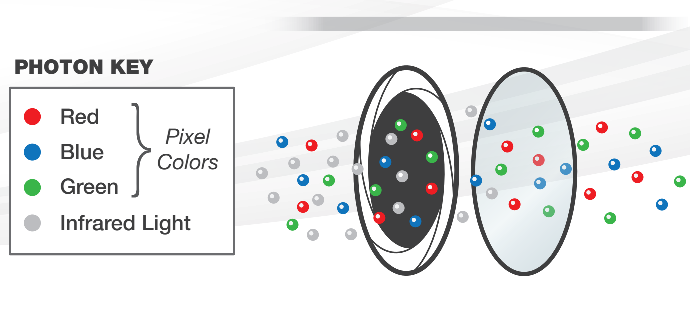
As a result of these considerations, a judicious selection of optical parameters to balance light collection, depth of field, and field of view is an important aspect of lens specification and design.

Infrared Cut Filter

Infrared (IR) cut filters improve color accuracy by blocking near infrared (NIR) photons before they reach the image sensor. Modern security cameras featuring true Day/Night functionality have switchable IR cut filters, which may be removed from the optical path for improving image quality at low light conditions. IR cut filters must be carefully designed so as to not attenuate light in visible wavelengths.

The two main parameters that describe the performance of IR cut filters are average pass-band transmission efficiency and transmission bandwidth. The average pass-band transmission efficiency refers to the percentage of energy in visible wavelengths transmitted through the IR cut filter without attenuation. Pass-band efficiency correlates with low-light performance. On the other hand, the transmission bandwidth refers to the range of wavelengths transmitted through the filter. The bandwidth design is a balancing act between low-light performance and color accuracy, and is best done by taking the red, green, and blue pixel quantum efficiency spectra (from the image sensor) into account.

Figure 2-2: Effects of IR Cut Filter on Light Collection



Infrared Removal
Infrared light is removed from the stream of photons passing through the iris for better color accuracy.

Image Sensor

The image sensor is the semiconductor chip that detects an image of the scene by using millions of closely packed pixels. Pixels are photodetectors that convert incoming photons into electric charges that are then converted into voltage, amplified, and finally digitized into bits.

The image quality for a given scene is related to the number of electric charges accumulated in its pixels. Image pixels with a small number of electric charges appear noisier than those with a large number of charges. Further, dim regions of a low-light scene often generate very small (or no) charges, which fall below the sensitivity of image sensor.

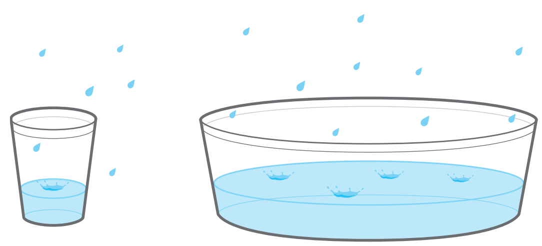
Advances in pixel design in recent years have made pixels smaller (down to a micron) and more efficient in collecting photons. Nevertheless, image sensors with larger pixel sizes continue to be useful due to their superior low-light performance. A pixel with a large size has more surface area to receive more photons and a bigger quantum well capacity to store more electric charges.

In addition to pixel size, exposure time and gain are two other important image sensor parameters that affect image quality under low light conditions.

Exposure time refers to the amount of time available to pixels for receiving light from a scene. Increasing exposure time leads to an improvement in light sensitivity and a reduction in noise. However, increased exposure time may also lead to motion blur and a reduction in frame rate.

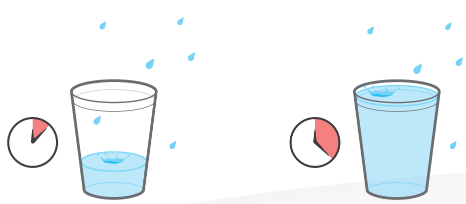
Gain, on the other hand, refers to the multiplication factor by which the signal from a pixel is amplified before transferring pixel data out of the image sensor. There are two types of gains, analog and digital. The difference between the two is that analog gain is applied before digitization of voltage into bits, while digital gain is applied afterward. Applying gain to a noisy signal boosts both the signal and the noise, resulting in a brighter but noisier image. Under low light conditions, analog gain is useful to boost pixel voltage to a large enough level so that it can be digitized effectively by the analog to digital converter of the image sensor. Doing so could show

Figure 3: Effect of Sensor Parameters on Light Detection



Pixel Size

Pixel size matters when trying to collect more light, especially in low-light conditions where photons are scarce. A larger pixel will collect more photons than a smaller pixel.



Exposure Time

A longer exposure time will also mean more photon collection, but this can result in motion blur.

Gain

As the pixels individually gather light, the photons are converted into electrons and digitized. In this process, Gain can be raised to increase the analog pixel voltage before the digital conversion process takes place, revealing more details as a result.

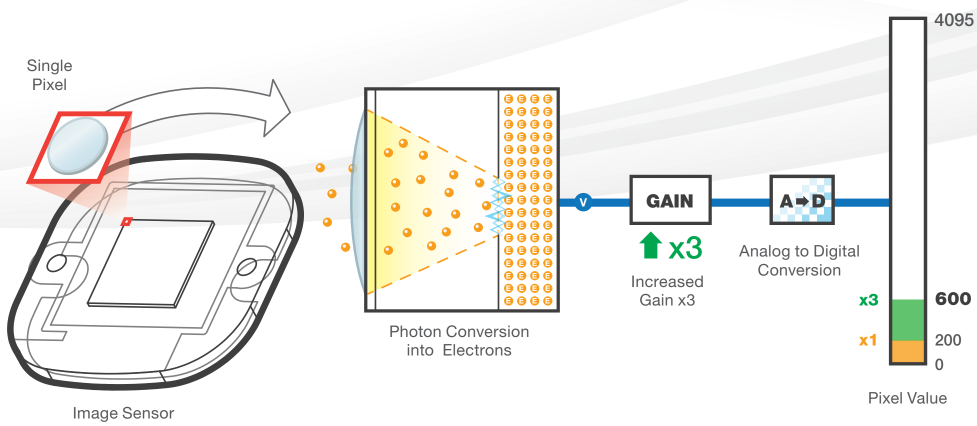
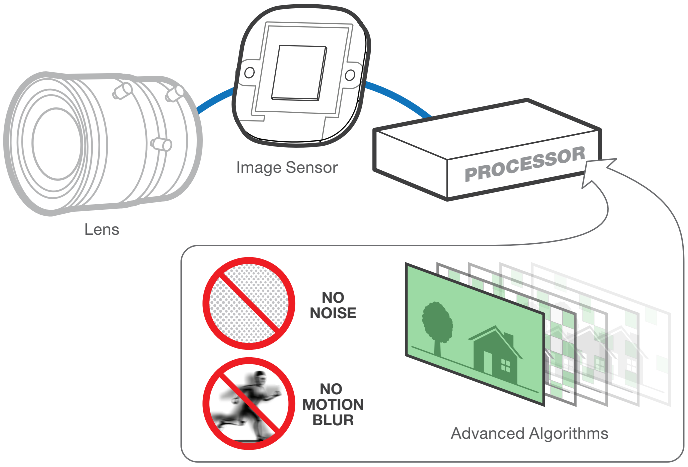


Figure 4: Advanced Video Processing Algorithms



Spatio Temporal Noise Reduction and Adaptive Contrast Enhancement

Arecont Vision's patent-pending smart processing algorithms collect relevant information from multiple video frames to reduce both noise and motion blur as new video is recorded.

new scene details that are otherwise too dim to be detected. Digital gain, on the other hand, boosts the already digitized pixel data. This may be used for improving the overall visibility of a low-light scene.

Processing

The raw images transferred out of an image sensor undergo several processing steps before they are streamed out of the camera. These processing steps serve to enhance image quality, and to compress the size of high resolution video to conserve network bandwidth and storage. Video processing algorithms can be used to minimize noise and also to improve color accuracy, sharpness, brightness, and contrast. Further, these algorithms can extract and analyze key image quality metrics and use them to control lens, image sensor, and processor parameters to further enhance images in future frames.

Quality and bitrate of videos are often considered as positively correlated entities, but this is not necessarily true in low-light imaging. Noiseless, high-quality videos have lower pixel variance between frames. This allows the high-quality videos to be compressed more effectively, which in turn results in a lower bitrate. In a low-light scene, it is therefore particularly important to employ advanced video processing algorithms to improve quality before the video is compressed. Without such algorithms, low-light videos either consume excessive network bandwidth, or significantly compromise image quality while encoding noisy video.

However, video processing algorithms should be carefully designed to not compromise other aspects of video quality, such as resolution. Without such care, these algorithms could blur fine scene details in their pursuit of reduced noise. Excessive and brute force use of these algorithms may also blur out fast moving objects. It is also important to implement these algorithms in a computationally efficient manner to operate with the hardware resources available to the camera.

Conclusion

Developed with a deep understanding of the different camera components affecting video quality, Arecont Vision's STELLAR™ technology allows color imaging under extreme low-light conditions. By improving video quality, while simultaneously reducing bitrate and storage requirements, Arecont Vision's STELLAR™ technology redefines possibilities in low-light imaging. ■

Figure 5: Light Level Improvements

Standard Color at 0.01 Lux **STELLAR™ at 0.01 Lux**

Zoom In Details

Leading the Way...

Arecont Vision is the leading manufacturer of high-performance megapixel IP cameras and associated software. Arecont Vision products are made in the USA and feature low-cost massively parallel image processing architectures MegaVideo® and SurroundVideo® that represent a drastic departure from traditional analog and network camera designs. All-in-one products such as the MegaDome® 2, MicroDome®, MegaBall®, MegaView® 2, SurroundVideo® and MegaVideo® Compact D4 series provide installer-friendly solutions. Compact JPEG and H.264 series cameras address cost-sensitive applications. These innovative technologies enable Arecont Vision to deliver multi-megapixel digital video at IP VGA camera price points. Arecont Vision is **Leading the Way in Megapixel Video** with cutting-edge innovation, superior performance, and the broadest selection of megapixel IP cameras.

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