LUMENERA **WHITE PAPER SERIES**

BUILDING AN OUTDOOR-READY VISION SYSTEM

Considerations when designing and implementing a smart imaging system tailored to your specific application requirements

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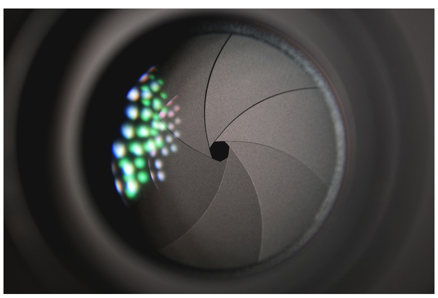
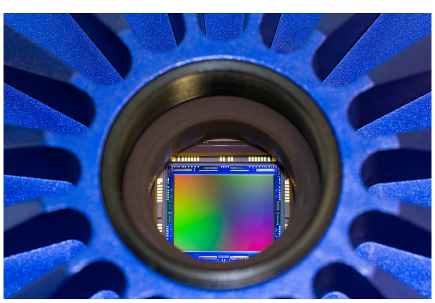




WHAT'S INSIDE

INTRODUCTION: BUILDING AN OUTDOOR-READY EMBEDDED VISION SYSTEM

Considerations when designing and implementing a smart imaging system tailored to your specific application requirements

The increasing convenience being experienced today as a result of the Internet of Things (IOT) and all-in-one connected solutions such as smartphones, smart watches, and tablets is transforming the way we use technology. This expectation of convenience is also influencing innovation in imaging systems with a goal of easy-to-use and powerful imaging systems through an all-in-one approach. While "smart cameras" are closer to the all-in-one solution we hope for, they often lack computing power, customization capabilities, or are too application-specific to be directed to other tasks. The key to a successful all-in-one imaging system is the use of embedded systems, especially when it comes to designing a custom and proprietary system.

Using separate components (the camera and the embedded computer) allows the system designer to select the best components currently available to meet the needs of their specific application. This document will walk you through key elements to consider when designing an embedded vision system that can then be tailored to your specific application such as high speed detection and analytics, image-based decision making robotics, aerial photogrammetry, or any number of other challenging outdoor imaging scenarios.

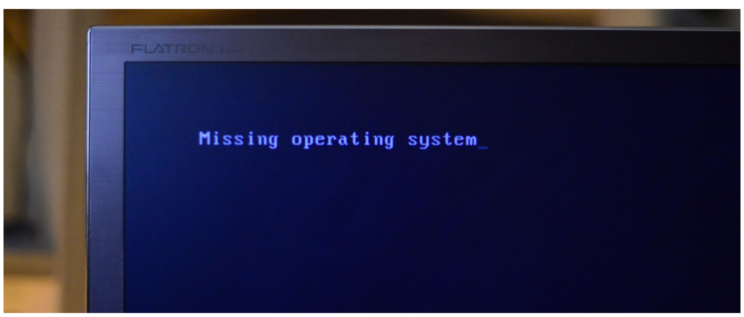
Additional documents on building application-specific embedded vision system are available on our website, with a focus on Intelligent Transportation Systems, Unmanned Systems, and Outdoor Intelligent Security. You can access them here: www.lumenera.com

COMPONENT ONE: EMBEDDED COMPUTERS

Embedded computers are the brainpower of the system (the ability to make it smart) and allow the system to make automated decisions, perform analytics on captured images, upload an image stream, upload results to a network connection, store the information locally (if the network connection goes down), and a number of other custom and proprietary tasks specific to the desired application.

These systems have come a long way from the days of coding instruction sets and low level programming. Many are capable of running full desktop versions of Ubuntu or Windows, which makes programming as easy as using your PC or laptop.

CONSIDERATION ONE: THE OPERATING SYSTEM



There are a number of operating systems (OS) to choose from when configuring an embedded vision system. Most embedded systems do not come with an OS, but they are pre-loaded with a variant of Linux and an option to upgrade to Windows (if the hardware supports this).

A popular alternative solution is to install an Android OS due to its open source nature and online third party support. While native versions of Android are not always available for specific embedded systems, third party bridging software exists to allow Android to run within the Linux OS as well as Android apps.

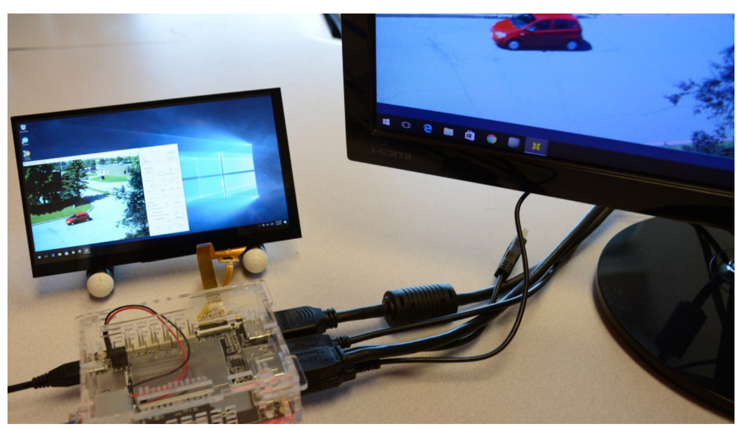
Odroid XU4	IoT	D	Y
Lattepanda	D	N	N
Nvidia TX2	N	D	N
Raspberry Pi 3	IoT	D	N
Minnowboard	D	D	Y

KEY
IoT: Windows Internet of Things Version
D: Full Desktop Version
Y: Yes
N: No

When selecting an OS and embedded platform, explore the online communities to determine if there is a sufficient amount of troubleshooting support that will meet your needs as a developer.

CONSIDERATION TWO: RUNNING WINDOWS

For the purpose of this document, we have chosen to demonstrate a system running Windows on the Lattepanda as it comes pre-installed with the full desktop version of Windows 10 Home. Many other embedded systems support different variants of Windows (Home, IoT, Embedded, etc.). The specific embedded system's website or community should be consulted to determine if it is suitable for running Windows.



In addition to the Lattepanda, we will be using a Lumenera Lt545R camera with this embedded vision system. The Lumenera camera requires Windows 10, DirectX and/or DirectShow. Some embedded systems do not come pre-loaded with the framework and it needs to be added.

The easiest way to add this software is to download Visual Studios and add the Windows SDK as a separate download from within Visual Studios. Installing the framework is essential before any Lumenera software can be installed on the device as links to the framework are created during the installation process. If Lumenera software is installed before adding Visual Studios, it will require an uninstall and reinstall for it to function properly.

TIP

Running a device in USB 3.0 mode on some (older) versions of Lattepanda requires a BIOS upgrade. See this post on their support page for further details.

CONSIDERATION THREE: SOFTWARE

The benefit of embedded systems that run Windows is the large availability of compatible software that will run on the embedded device. Aside from the Visual Studios mentioned earlier, other great development environments exist. A favorite among embedded system developers is Qt (www.Qt.io), a cross-platform framework that allows you to develop one piece of code that can be compiled for systems running Windows, Linux, MacOS, Android, and iOS.

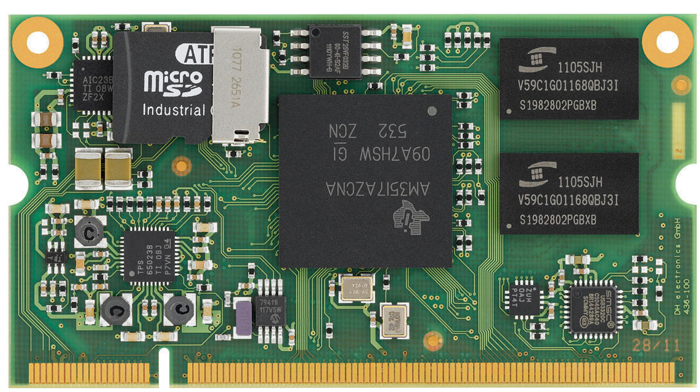
Both Qt and Visual Studios, along with a number of other development environments, support the usage of OpenCV. OpenCV is an open source computer vision library with a strong community of over 47,000 contributors. It is supported on Windows, Linux, MacOS, Android, and iOS, and has interfaces for C, C++, Python, and Java.

Although the previous section focused on the Windows OS, it is important to note that the cross platform nature of Qt and OpenCV make them great development options regardless of the chosen operating system. They also allow solutions to be portable, enabling simultaneous development on a number of operating systems with little to no change in code.

CONSIDERATION FOUR: SCALABILITY

OPTION ONE: COMPUTER ON MODULE (CoM)

Computers on Modules (CoM) should be considered when rolling out a large scale production of the system as it can be overwhelming. A CoM is a single board computer without interface ports such as USB, Ethernet, or HDMI. It has only the basics required for computing: CPU/GPU, RAM, and an SSD. The CoM is then paired with a custom carrier board containing only the interfaces required for the system. This allows the design to be cost effective and maintain a smaller



Source: Wikipedia

Computer on Module

profile, requiring smaller enclosures and less overall weatherproofing for outdoor systems. CoMs are also manufactured with product integration in mind and therefore available for a number of years to prevent having to redesign systems each time an embedded system manufacturer upgrades/changes their product.

If images are to be:

- collected by a single camera,
- processed in real time by OpenCV,
- processed results sent to an offsite location,

the only interfaces required are a USB port for the camera and a Wi-Fi transmitter for a downstream connection. Since the Wi-Fi connection allows remote access, there is no need for additional USB ports for peripherals like a keyboard and mouse or an HDMI port for a display. This allows for the creation a small custom carrier board with a single USB port, an antenna for Wi-Fi, and an input power connection.

OPTION TWO: YOCTO PROJECT

The Yocto Project merits some attention for those looking for a barebones operating system with only the functionality they require. This initiative helps create custom distributions of Linux based on the project's requirements, using templates, tools, and methods. It includes free tools such as emulation environments, debuggers, and application toolkit generators, and provides a wealth of information and documentation for new users and advanced developers alike.

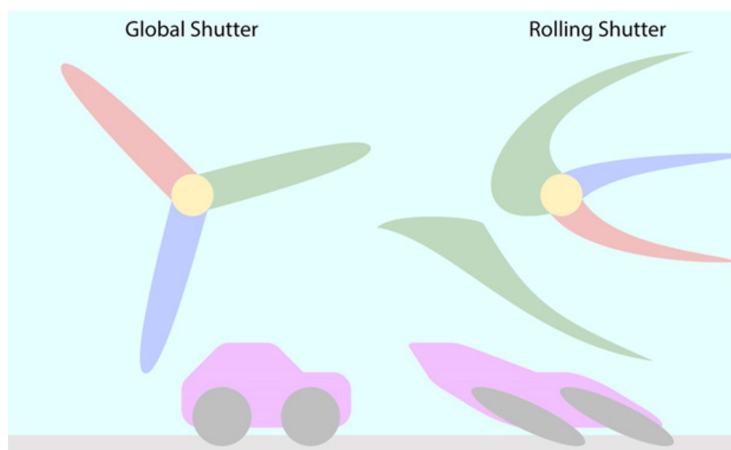
The Yocto Project also supports builds for a number of architectures including ARM, x86, x86-64, PPC, and MIPS. Furthermore, it offers an Eclipse IDE plugin and a Graphical User Interface (GUI) to the build system.

COMPONENT TWO: THE CAMERA

Cameras that operate outdoors have to perform in some of the most challenging lighting conditions. Varying light is one of these challenges and it can even vary within a single frame. Along with this challenge comes a number of other factors to consider when imaging outside. This section will address what aspects of a camera need to be optimized for outdoor imaging to allow you to choose the right camera for your application. More application-specific information is available for solutions incorporated in Intelligent Transportation Systems (ITS), Unmanned Systems, and Outdoor Intelligent Security.

CONSIDERATION ONE: SHUTTER TYPE

Most digital cameras will have an image sensor with one of two types of shutter: rolling or global. Rolling shutters capture images by exposing the pixels on the sensor one line at a time in a sequential fashion where-as global shutters expose all of the pixels at the same time. This is explained in further detail in our white paper on designing a vision system.



The importance of undertanding shutter types is that sensors using a rolling shutter can have image artifacts or distorted objects when either the subject or the camera is in motion. The higher the speed, the more pronounced the distortion.

Global shutters are a great way to eliminate this phenomenon, but often at the expense of framerate, noise, and sensitivity. All things being equal, rolling shutters can operate at higher speeds than global shutters, will have lower noise, and are more responsive. It is important to consult the actual specifications of a camera to compare framerate, noise, and sensitivity.

CONSIDERATION TWO: FRAMERATE

A number of camera applications benefit from accelerated framerates. A greater framerate allows for a higher sampling frequency, which is crucial for high-speed detection and analysis. Also, a high sampling rate is important for detecting a certain condition and triggering an event via the embedded computing system. Software triggers are often easier to implement and require less costly infrastructure than hardware triggers.

> **TIP**
>
> As per the Nyquist theorem, a frame rate of at least double the desired sampling rate is required to ensure events are properly captured and recorded.

CONSIDERATION THREE: BIT DEPTH

Bit depth specifies the amount each pixel is sampled. Most people are familiar with the principle of resolution – the higher the resolution, the finer the detail that can be reproduced. Bit depth is not dissimilar to resolution, but helps resolve a higher variance in pixel intensity with higher bit depths as opposed to visual detail in the image.

In other words, selecting a certain bit depth determines with what accuracy you are choosing to measure the electrical charge in the pixel. Higher bit depths are crucial for detecting extremely slight variations in colorthat are imperceptible to the human eye. Many outdoor applications do not require a bit depth greater than 8-bits, unless they are performing precision measurements such as photogrammetry or color analysis.

For a more complete explanation of bit depth, read our blog post titled "An In-Depth Look at Bit Depth".

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CONSIDERATION FOUR: DYNAMIC RANGE

Dynamic range is what determines a camera's ability to make out detail in very bright and very dark areas of a single image. When imaging outside this is a common challenge as the difference of intensity between sunlit portions of the scene and dimly lit shadows can be staggering.

This challenge can be overcome with a camera that has a wide dynamic range. Increasing gain or exposure time will saturate the brighter portions of

of the scene and decreasing them will remove definition from the darker areas. Using a look-up table or adjusting the camera's gamma curve could help bring out some detail in the darker and lighter areas of the image, but they are no match for a camera with a wider dynamic range.

Wondering what the difference is between Dynamic Range and Signal to Noise Ratio? Read our blog post here that outlines the differences.

CONSIDERATION FIVE: NOISE

Noise has its biggest impact on dimly lit scenes where the signal to noise ratio is greatly reduced. To compensate, exposure time is typically increased along with gain. Since exposure time cannot be increased past a certain point while reliably capturing motion, gain is often the parameter of choice used to brighten a dimly lit scene. However, by increasing the gain, noise in the image is also increased and, therefore, produces a noisy image. This is outlined in our blog post contrasting exposure time and gain.

Camera Characteristics	
Sensitivity	Mono: 5.0 DN/(nJ/cm2), Color: 4.5 DN/(nJ/cm2) (Global and channel gains at unity)
Dynamic Range	~72.9 dB
Full Well Capacity	~ 10,500 e-
Relative Responsivity	64%@ 520nm (color), 70%@ 530nm (mono)
Read Noise	~2.37 e-
Dark Current Noise	1.4 e-/s (at 22 °C ambient, 35 °C internal camera)

Selecting a camera with low noise is very important for capturing reliable image data while in low light. The specific particular noise specification to focus on is read noise. Due to a relatively short exposure time, dark current noise (measured in electrons/second) is much less impactful than read noise (measured in electrons). Read noise occurs each time an image is captured, regardless of the length of the exposure time. The higher the read noise, the more noise you will have in a dimly lit scene, especially at high gain values.

COMPONENT THREE: LENSES, LIGHTING AND FILTERS

Beyond the camera and the embedded system, there are a number of imaging components that should not be overlooked. First and foremost, the camera needs a lens. Following this, certain applications will require external lighting sources to add light when the sun is insufficient. Other applications will also benefit from filters to remove certain wavelengths of lights that are superfluous to their application.

This section will address each of these components to help you decide on what is best for your application. These components will also be revisited for solution specific applications such as ITS, UAV, and intelligent security.

CONSIDERATION ONE: LENSES

When selecting a lens, there are a number of important considerations such as: working distance, required field of view, the camera's sensor size, and its resolution. To determine the type of lens required for your application we recommend consulting our white paper for selecting a lens for a vision system. It will help you determine the lens' required focal length, resolution, and sensor size compatibility. This lens options below will put forth considerations to take into account for imaging outdoors.

OPTION ONE: DAY/NIGHT LENSES

One of the main factors to consider with lens selection will be the time of day the system is to be used. If the system will be used at all hours of the day, a day/night lens will likely be required. Day/night lenses are infrared (IR) light-corrected for use with IR lighting during the overnight hours. Additionally, multispectral applications that use both visible and infrared light would require an IR corrected lens.

OPTION TWO: VARIABLE IRIS LENSES

Outdoor applications have some of the most challenging lighting conditions due to the variability and unpredictability in light intensity. Using a variable-iris lens introduces another parameter that can be configured to manage the brightness of a scene.

New to the machine vision market are precision iris lenses known as P-Iris lenses. They utilize a very precise stepper motor to accurately set the aperture to the required setting. They are far more accurate than their predecessor, DC-Iris lenses, and are not plagued with the inability to maintain an iris setting, which was commonplace for DC-Iris lenses.

CONSIDERATION TWO: LIGHTING

When selecting a lens, there are a number of important considerations such as: working distance, required field of view, the camera's sensor size, and its resolution. To determine the type of lens required for your application we recommend consulting our white paper for selecting a lens for a vision system. It will help you determine the lens' required focal length, resolution, and sensor size compatibility. This lens options below will put forth considerations to take into account for imaging outdoors.

As mentioned earlier, if using an IR light source, it is crucial to use IR corrected optics to ensure a sharp image is captured across the entire range of wavelengths. If no IR lighting is used, a day/night lens can be omitted from the selection criteria.

Source: Flickr

Regardless of the wavelength of light that is used, it is important to have a reliable trigger for the light to ensure that the strobe fires when the camera is exposing. A camera-based trigger would be preferred over a trigger coming from the embedded system as there will be little to no latency between the camera and the strobe. If the embedded system triggers both the camera and the strobe simultaneously, there could be some delay between the triggers due to other processes running on the embedded system and will result in a poorly lit scene.

Again, the use of a P-Iris lens versus a DC-Iris lens is recommended once the camera and light source are calibrated for overnight image capture. There is a much higher degree of reliability that the P-Iris will consistently use the proper aperture setting. Images will be more consistently exposed, reducing and possibly eliminating the need for post processing.

CONSIDERATION THREE: FILTERS

Filters are a great way to reduce glare or isolate particular wavelengths of interest for inspection applications and should at least be considered in any new vision system design. They help by increasing relevant signal to noise ratios and make image analysis easier for the embedded computing system.

In urban applications, polarizing filters are very useful to reduce glare from the sun. This allows cameras to see through glass and reduce glare for easier color detection. In the photo below, the car has a more uniform red color when using a polarized lens and the interior of the car is much more visible. It is also important to note that polarized filters remove roughly 50 per cent of the light, so lots of light or a more sensitive camera is helpful when using them.

Source: PictureCorrect Photography Tips and Techniques

Other filters (such as double and triple bandpass filters) exist for specialized, multispectral applications. Here, a few specific wavelengths are isolated and run through algebraic equations to perform analysis on the scene. There also exists visible + NIR filters that allow for a very narrow band of NIR light from a strobe to pass through to the camera for overnight operation (as discussed above). The camera's NIR-cut filter would be replaced with such a filter allowing a color camera to be used with an infrared strobe. However, it is important to note that this method would result in a decrease in color accuracy because the infrared light from the sun during daytime operation would adversely impact the color response of the camera.

THE IMPORTANCEOF CONSIDERING EMBEDDED COMPUTERS, CAMERAS, LENSES, LIGHTING AND FILTERS FOR YOUR OUTDOOR-READY EMBEDDED VISION SYSTEM

Imaging systems that combine an embedded computer and camera have a number of advantages over centralized computing and are becoming incredibly popular as the cost of embedded systems comes down. Embedded systems can perform near real-time analytics, make decisions using neural networks, and communicate results, instead of just sending raw data back to a centralized datacentre.

When designing a system with an embedded computer, careful consideration needs to be made when selecting software and hardware. Open source communities such as OpenCV are becoming incredibly reliable and it is becoming harder to justify spending money on software when open source applications are just as good as licensed software.

When selecting a camera for an outdoor-ready embedded system, the following requirements can serve as a checklist:

- If motion is involved, a global shutter will prevent image distortion.
- High framerates are desirable when running analytics or using software-based rules to trigger events.
- A large bit depth is required for performing precision measurements or color analysis.
- A wide dynamic range is essential for capturing data in brightly lit areas of a scene and in the shadows simultaneously.
- Finally, read noise should be minimized to allow for more gain to be used in low light situations.

Other considerations surrounding the lens, filters, and lighting should also be made:

- A variable iris lens will help add a degree of freedom when exposing frames in changing lighting conditions.
- Use of a P-Iris lens will ensure precision and reliability when selecting aperture values.
- If using additional infrared lighting or for multispectral applications stretching into the near infrared, a day/night (IR corrected) lens must be used to correct for chromatic aberrations which would reduce sharpness in the image.
- Filters can also help increase SNR at key wavelengths or reduce glare in images, allowing the camera to see through glass and register more accurate colors.

Although this is not an exclusive list of considerations for choosing an outdoor-ready embedded vision system, this overview of high level requirements is a first step in helping you identify the correct set up.

Lumenera understands your imaging needs and we're here to help you get the most out of your camera whatever the imaging application. All Lumenera cameras come with a four year warranty and are supported by an experienced team of technical support and imaging experts.

If you require any assistance in selecting a camera or other components of your vision system, our knowledgeable camera specialists will be happy to assist you. Contact them at info@lumenera.com.