Digital Cameras in Unmanned Aerial Vehicles (UAV) for Military and Commercial Uses

Lg11059 offers complete imaging solution for the growing UAV market

Background

An Unmanned Aerial Vehicle (UAV) is an aircraft that flies without a human pilot onboard, controlled remotely or flown autonomously via pre-programmed flight plans or other automated guidance systems. Traditionally, UAVs were largely deployed in military missions, but are increasingly being adopted by civil applications including firefighting, law enforcement, assessment of natural disasters and environmental monitoring.

The modern UAV originated in the 1970s, motivated by the military's need for a safe way in which to fly over high risk areas without endangering a pilot's life. These flying missions would also benefit from a smaller, covert vehicle compared to a manned aircraft. Engineers in the United States started experimenting with smaller, slower, cheaper UAVs that mimicked large model airplanes. Their most important feature was the inclusion of small video cameras that could send images to ground-based operators in real-time. Work progressed through the 80s and early 90s as vehicles became larger and more capable, leading to a successful, wide deployment in the mid-90s. Thanks to their reconnaissance and tactical capabilities, UAVs are now a major component of the global war on terrorism.

UAVs are extremely flexible devices, and can be used for a variety of applications beyond current military, counterterrorism and law enforcement requirements. Technology development for civil applications began to emerge in the 1990s. Today, a wide range of international public service agencies and private corporations rely on UAVs for diverse, civil and commercial uses. UAVs are also an emerging business for the defence industry with a large potential for growth, at a time when the military worldwide is looking to cut back on big-ticket purchases such as fighter jets and navy ships. Combined with the aforementioned applications, the demand for UAVs in general and imaging cameras in particular is growing.

Architecture

The imaging subsystem of a UAV relies on a variety of enabling technologies including sensors, computing devices and wireless communications. A typical platform would comprise of multiple digital cameras that interface to a geospatial processor. Georeferenced imaging data is distributed through a data networking switch fabric, making system configuration simple, extensible and flexible. The control computer is used to trigger the camera, store and prepare images for transmission while recording data such as camera settings, altitude and position that are attached to images as metadata. The data is then sent to the UAV ground station via a state-of-the-art wireless network capable of achieving real-time wireless data retrieval of large files. Modern UAVs are capable of capturing and streaming multi-megapixel, large format images and metadata.

The imaging control computer is normally decoupled from the flight control computer, with the two computers exchanging information in real time. Flight path and other mission requirements are programmed by ground station engineers into the mission planning software that feeds the autopilot with the data necessary to direct and control the aircraft during the mission.

Multiple cameras can be combined into a unique assembly to increase the sensing capabilities of the UAV system. A modular mounting scheme allows for multiple camera modules to be configured on a single camera frame assembly to suit the need of a specific mission. The multiple camera approach can be used to acquire a mix of colour, false colour and monochrome images covering the same target area. The cameras optical axis must be parallel to one another and their shutter synchronized to operate simultaneously. Image processing is then used to fuse together the various images to generate a single, highly detailed, color image.

Multiple cameras are also used to acquire oblique images, where typically one vertical and multiple oblique cameras are used simultaneously. The images produced by these systems allow for the three-dimensional reconstruction of a scene. The unique angles depicted in the images of ground features provide axial information of vertical sides.

Multiple cameras can be positioned in an array to allow full 180° high-definition snapshot images on the fly. This means that the system can take a single picture of an entire scene pulling vast amounts of information from the captured image. The level of detail and picture accuracy from this multi-camera approach far exceeds what would be possible from a single camera when combined with a wide angle lens, as a lens can introduce aberrations and reduce the level of detail at or near the edges of the image.

The downward facing cameras in the UAV can be used for orthophotography applications, an aerial photography technique that creates an image where the scale is constant over the entire image. Because the scale does not change with position on the image, it is possible to make accurate measurements of angles, areas and distances using relatively simple calculations. For this technique to work, the downward facing camera must be perfectly aligned to a 90 degree angle relative to the ground.

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Camera Requirements

Cameras used on UAVs face a set of application requirements very specific to the industry. Traditionally, airborne digital cameras have been subdivided into three specific categories:

- Small format - cameras equipped with up to 16 megapixel sensors;
- Medium format - cameras utilizing sensors between 16 and 50 megapixel; and
- Large format - cameras deploying large sensors with more than 50 megapixel.

The line between small, medium, and large format sensors has shifted over time and will continue to shift or even blur. For example, companies advertise medium format cameras that have a larger footprint than their previous large format cameras. The definition was originally based on the size of the sensor. In past, a small format (35 mm) camera sensor measured 24 x 36 mm, up to 60 x 90 mm was considered a medium format, and everything bigger was large. Cost points across categories are also very fluid, opening new possibilities as capabilities increase in what would have been otherwise considered entry level, small format cameras. To further add to the confusion, a 35 mm sensor is considered small in the aerial camera industry, but large in consumer and machine vision industries.

Small format cameras are usually: a) area array (full frame) cameras equipped with CCD or CMOS two-dimensional arrays; and b) monochrome or coupled with mosaic RGB filters to produce colour images or IR filters for false-colour images. Larger format cameras are typically used as stand-alone sensors for traditional wide-area mapping applications or high altitude systems, while medium format cameras are often used to augment LIDAR data.

There are a set of performance features that need to be taken into consideration when it comes to digital cameras used in UAV applications. The rest of this document discusses those in detail.

Superior Image Quality

The aerial imaging community utilizes the National Imagery Interpretability Rating Scale (NIIRS) to define and measure the quality of images and performance of imaging systems. Through a process referred to as "rating" an image, the NIIRS is used by imagery analysts to assign a number which indicates the interpretability of a given image. The NIIRS concept provides a means to directly relate the quality of an image to the interpretation tasks for which it may be used. Although the NIIRS has been primarily applied in the evaluation of aerial imagery, it provides a systematic approach to measuring the quality of photographic or digital imagery, the performance of image capture devices and the effects of image processing algorithms.

Image quality is the result of multiple design choices in a digital camera. A larger sensor provides a means to capture more light as a result of having larger pixels. Better image quality is achieved more easily with larger pixels on sensors. CCD sensors perform better than CMOS sensors as the latter are noisier and offer a lower dynamic range. A 35 mm CCD-based digital sensor is required to provide the level of image quality expected in a small form factor aerial camera. For comparison, consumer cameras or cell phone cameras use very small sensors with tiny pixels and are based on CMOS technology which cannot approach the level of quality required for UAV applications.

High Resolution

High resolution sensors are required to provide the level of detail needed from an aerial image. Higher resolution cameras do not require stitching together multiple lower resolution images to cover the same geographic footprint. Image Stitching necessitates multiple image manipulations so as to address proper color balancing across all the images caused by variations in light sensitivities in each camera and pan-sharpening techniques to address the different focal points of each image. The end result can be a poorer quality image compared to a single, higher resolution CCD.

One of the benefits of increased resolution is the need for less aircraft flying lines to cover a target area that in past required more. This translates into lower costs and increased operational benefits. Also, missions can be flown at higher altitudes while still capturing the same level of detail needed for the tactical assessments, a benefit for covert operations.

Reliable Camera Shutter

Electronic shuttering is required over mechanical shuttering as the latter uses a mechanism that is prone to early failure. Reliability is paramount in UAV applications as failed military missions can have significant costs implications or dire consequences for troops on the battle field.

Global shutter is a necessity as it avoids image skew. It is caused by a difference in the exposure time between the first and last row of the pixel array matrix on the camera's sensor.

Smear can also occur with shutters that are not opaque enough to block out all of the light. When a sensor has a poor shutter, bright light can leak into the pixels before the start of image integration, thus filling up the pixel wells with electrons causing a light streak above a bright portion of the image. If this same bright area saturates the pixels, a downward smear can be seen in the image as these pixels overflow into the sensor's shift registers when the image is being clocked out. The end result is a streak below the bright area. When combined, both of these artefacts can cause an entire column of pixels to bloom white.

Image Format

Images must be acquired in a RAW format. A raw image file contains the least processed output from a digital camera's image sensor. This allows you to see exactly what the camera is seeing, without losing any information during processing. Raw images give a great amount of flexibility by allowing users to precisely control the brightness, contrast, sharpness and other variables during image analysis, rather than during image capture. Raw image files have 12 or 14-bits of brightness information per pixel, as opposed to the 8-bits per pixel in a JPEG compressed image, and can render finer details due to the additional information each pixel bit contains.

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Blur-Free Images

The system needs to guarantee blur-free images in each particular flight condition. Surrounding conditions can vary wildly from mission to mission with light levels, in particular, being unpredictable. Lower light conditions require longer exposure times to capture quality images from the camera, resulting in a blur in the image as the UAV is in constant motion. A highly sensitive camera allows for quick exposure times to capture the same intensity in the images, and even under low light conditions there is a guarantee of blur-free images.

Low Noise

The sensitivity of a camera is dictated by the minimum light signal needed by the sensor for detection. This parameter is strongly influenced by the amount of noise produced and present in the image. It is important for cameras working in low light environments such as UAV applications to have minimal noise so as to maximize the light detection of the sensor. The noise of a camera sets an ultimate limit on the camera sensitivity. Digital cameras are therefore often compared using their various noise specifications as noise is derived from multiple sources. A low noise, high sensitivity camera will perform best for UAV applications.

Fast Frame Rates

Superior cameras should offer the highest frame rates possible for the desired resolution. Creating imagery of a scene involves taking multiple images that are then stitched together. Higher frame rate image capture provides more flexibility in determining how much overlap can be made available between adjacent images, as a higher number of images can be captured for a given flight speed. This parameter must match the flight plan computer as the UAV speed must be equivalent to how fast the camera can capture images. For comparable altitude and field of view, a camera with faster frame rates allows for higher UAV travel speed, providing the benefits of shorter flight times and increased covertness.

Large resolution and high frame rates must often be traded off against each other in digital cameras. Specialized image sensors that perform far beyond the capabilities of comparable consumer-type products are required in order to achieve both high frame rates and large resolution. Finally, the camera's data interface can also limit the resolution and frame rates for UAV applications, as the volume of data coming from the camera must be transported to the other mission critical components in a timely manner.

Flexibility

System flexibility is particularly important to tailor the performance of the UAV and keep costs under control. This translates into the ability to provide interchangeable cameras and lenses for a variety of mission criteria. As discussed earlier, flexibility can be achieved through the use of standard data interfaces, which can be used in conjunction with a common software architecture that supports a range of cameras. This allows interchanging cameras without having to rewrite the control software every time improvements are made or a different camera architecture is needed. This is very valuable for small and medium-sized organizations which are coping with a wide range of applications while trying to reduce their operating costs.

Standard Data Interface

In order to allow a fast transfer of the image data, the camera must be equipped with a high-speed data interface. An industry standard data interface will allow a mix-and-match of modules, each with a specific function, for example the flight computer, image storage, communication to ground controllers just to name a few. The UAV requires efficient ways to extract, process, analyze, store and distribute the massive amounts of data that the latest generation of high resolution cameras generate.

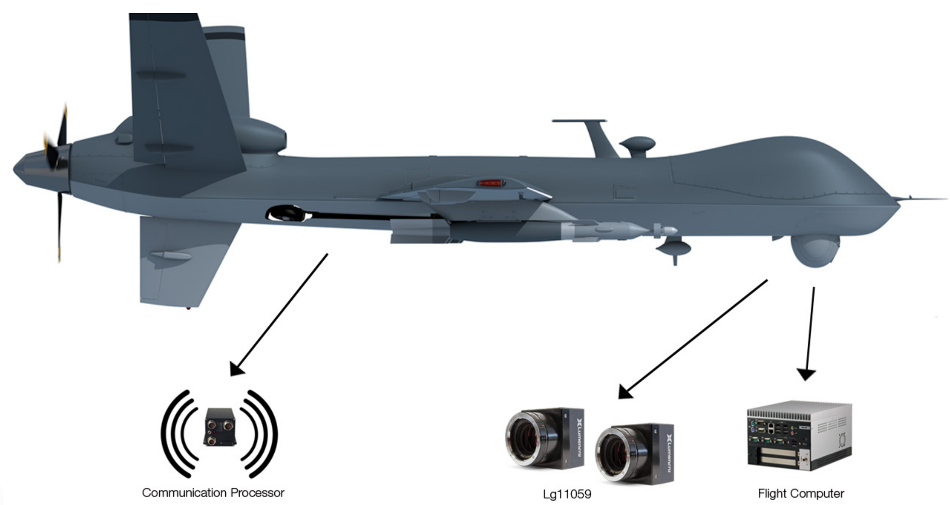
Gigabit Ethernet is a data network technology ideal for UAV applications and commonly used today. Future systems might come to rely on faster variants such as 10 Gigabit Ethernet as the race towards even higher camera resolution and increased system capabilities keeps progressing. Smaller UAV applications might be satisfied with a single onboard computer using a USB bus to communicate with peripherals including the camera, especially with the advent of the USB 3.0 specification that presents data throughput rates that exceed Gigabit Ethernet.

Robust Construction

UAVs present a challenging operational environment for digital cameras. They need to be robust enough to sustain the shock and vibrations during operation of the system. They must also be light and compact enough to reduce the payload on the aircraft. These stringent requirements can be pushed to extreme and can lead to the use of military-grade components for some applications. The cost of military UAVs is orders of magnitude greater than that where their use in civil applications does not make economic sense. For civil applications, commercial grade cameras designed in a robust and compact package are normally sufficient. Even when it comes to military equipment there is a definite trend toward using Commercial Off The Shelf (COTS) components whenever possible as militaries worldwide face tougher budget constraints, thus opening the door to well made commercial cameras for some military UAVs.

Lens Options

The increase in camera resolution presents a challenge for manufacturers to supply lenses that will support higher resolutions with the right performance level. Improvements in camera technologies force equivalent improvements in lens optics. As camera resolution increases, distortions or aberrations in the glass become much more apparent in poorer quality lenses. For this reason, it is important as a lens manufacturer to use higher quality glass within lenses designated for use on higher resolution cameras. The lens mount on a camera should have the right mounting and control features to support a rich family of quality lenses. Lens control for focus, iris and zoom settings should be built right into the camera so that settings can be adjusted either automatically or remotely as scene conditions vary throughout the mission.



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Lumenera’s Lg11059 Camera

The Lg11059 is an 11 megapixel camera that provides 5 fps at full 4008 x 2672 resolution. This industrial-grade camera with a 35 mm high resolution CCD sensor and a fully integrated Canon EF lens controller makes it an ideal solution for demanding environments such as UAVs. Additionally, a fully global electronic shutter takes a snapshot at a precise moment where all rows are captured at the same time and light intensity, resulting in high-speed images with zero blur.

The Lg11059 camera utilizes its high quality CCD sensor to its maximum by providing either vivid color or very sensitive visible light and near IR monochromatic images. Full streaming of uncompressed video along with still image captures are easily controlled through our standard API interface or through the GigE Vision interface. Region of interest and binning modes allow the camera to run at faster frame rates (14 fps at 640 x 480 resolution) while providing only the needed image data. Image capture synchronization is achieved using either a hardware or software trigger, and is complemented by 32 MB of on board memory for frame buffering to ensure image delivery.

The robust and compact design of the Lg11059, measuring 76.2 x 76.2 x 82.6 mm, makes it ideal for installation into compact systems where space is at a premium. The fully locking Gigabit Ethernet cabling, power connector and digital I/O interface ensure a simple plug-and-play installation, minimizing camera clutter with only one standard cable. Simplified I/O cabling is provided through a locking Hirose connector supporting 4 output and 3 input ports that can be automatically or manually controlled through software. The use of locking connector ensures reliable operation even under high vibration environment. The camera is void of fans or cooling holes further increasing reliability.

SDK Application

The Lumenera Camera SDK provides a full suite of features and functions that allow you to maximize the performance of your camera within your application. The SDK is compatible with all USB and GigE based cameras. Microsoft DirectX/DirectShow, Windows API and .NET API interfaces are provided allowing you the choice of application development environments from C/C++ to VB.NET or C#.NET. Full inline IntelliSense autocompletion and documentation is provided with the .NET API interface and is accompanied by a full API manual describing all the camera functions and properties.

Highlights

- Lumenera’s Lg11059 offers is an 11 megapixel camera that provides 5 fps at full 4008 x 2672 resolution
- Provides either vivid color or very sensitive visible light and near IR monochromatic images
- Full streaming of uncompressed video along with still image captures are easily controlled

About Lumenera

Lumenera Corporation, a division of Roper Technologies, headquartered in Ottawa, Canada, is a leading developer and manufacturer of high performance digital cameras and custom imaging solutions. Lumenera cameras are used worldwide in a diverse range of industrial, scientific and security applications.

Lumenera solutions provide unique combinations of speed, resolution and sensitivity in order to satisfy the most demanding digital imaging requirements. Lumenera customers achieve the benefit of superior price to performance ratios and faster time to market with the company’s commitment to high quality, cost effective product solutions.

For further information about Lumenera, please visit www.lumenera.com

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