Continuous Wave Laser Illumination:

The Clear Choice over Thermal Imaging for Long-Range, High-Magnification Night Vision Perimeter Protection

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VUMii

Contents

Vumii Inc. • 1100 Abernathy Road • 500 Northpark Town Center • Suite 1100 • Atlanta, GA US 30328
+1 678 578 4700 tel • +1 678 578 4710 fax • www.vumii.com

Executive Summary

Today's physical security professionals in transportation, critical infrastructure and government organizations are increasingly tasked with not only detecting objects at night, but also with investigating, interpreting and responding to criminal and terrorist threats. A key part of addressing the challenges of securing facilities, perimeters and borders is integrating or deploying long-range capabilities that allow for personnel to more easily identify targets, particularly at distances of more than 500 meters.

Two leading night vision technologies – thermal imaging and continuous wave laser illumination – are generally considered by groups seeking security solutions that best fit their needs and goal. Experts understand there's a complex checklist to review before any technology decision can be made. Important considerations include comparing a number of attributes such as scalability, magnification, pixel performance, zoom capabilities, versatility, maintenance, and controllable light sources.

Such an evaluation quickly reveals the strengths and weaknesses of each technology and which one is up to the task of best identifying targets, recognizing facial features and reading license plates and ship identification numbers at distances up to 3000 meters.

This white paper, "Continuous Wave Laser Illumination – The Clear Choice over Thermal Imaging for Long-Range, High-Magnification Night Vision Perimeter Protection" defines, provides a historical reference, and closely examines the two technologies, allowing decision-makers to assess the criteria necessary for evaluating and ultimately purchasing the right night vision system for a variety of environments. Specifically, this white paper highlights how continuous wave laser illumination systems provide better long-range visibility to any type of target and why using conventional thermal technology for distances greater than several hundred meters may actually hinder the ability to view potential security threats.

Thermal Imaging and Continuous Wave Laser Illumination Defined

Before comparing night vision technologies, it is important to understand how such solutions operate. The section that follows defines thermal imaging and continuous wave laser illumination systems and how each differs in the way it operates and ultimately assists security personnel.

Thermal Imaging

Thermal imaging provides the ability to see potential targets in situations where little to no light is available by utilizing variations in temperature to create images.[i] Thermal sensors detect radiation in the infrared range of the electromagnetic spectrum. Images are then produced based on the radiation that is emitted. Infrared radiation is emitted by all objects based on their temperatures, and the amount of radiation that is emitted by a particular object increases as temperature increases. Thermographic cameras are then used to view objects, and warm objects are easily noticed when viewed against cooler backgrounds. Therefore, humans and other warm-blooded animals are easily detected.[ii] The most common thermal array size is 320 x 240 pixels. Pitch size in microns relates to the size of the effective pixel in the thermal sensing array. The lower the pitch, the more detail can be shown. The best thermal sensors offer pitch sizes of 25 microns or smaller.

There are two general categories of thermal imaging devices: cooled and uncooled. Cooled devices have elements sealed inside a container that keep them at temperatures below zero degrees Celsius. Cooled systems use a specialized lens and are able to sense higher contrasts of radiated thermal infrared information. On the other hand,

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uncooled systems lack such a special lens and contain solid-state sensors that are less sensitive than their cooled counterparts. Although uncooled technology is continuing to improve, cooled systems provide more detailed images while the lifespan and total cost of ownership of uncooled systems is superior.[iii] Uncooled thermal arrays are available at 640 x 320 pixels equivalent to 4 Common Intermediate Format (CIF) video. Megapixel resolution is not available at this time and is unlikely to be available in the future.

Thermal imaging systems are based on a fixed focal length lens or may use up to three multiple fixed focal length lenses. By the nature of the thermal sensor core technology, continuous zoom magnification is very rarely available.

Continuous Wave Laser Illumination

Continuous wave laser illumination systems utilize highly-controlled, relatively far-reaching, near-infrared active illumination to provide a reflected image in complete darkness with a more standard image capture technology such as Charge Coupled Device (CCD) or Complementary metal–oxide–semiconductor (CMOS). Based on an innovative, near infrared, continuous-wave laser beam, continuous wave laser illumination technology dynamically and automatically synchronizes to an integrated CCD imager with associated optics and filters. By producing its own invisible light source of approximately 810nm wavelength, continuous wave laser illumination technology produces near-optical contrast imagery, in which markings can be read and people can be recognized from zero light to full daylight. With high magnification capabilities of up to 60 times through the use of a continuous optical zoom lens, the ability to see through windows or windshields at night is possible. Continuous wave laser illumination technology is versatile as it produces high resolution court admissible video, requires minimal training, and has a low maintenance costs.

A brief history of thermal and continuous wave laser illumination can be found at the end of this white paper.

Comparison of Technologies

With a firm understanding of the two individual technologies, the remainder of this white paper will focus on comparing and contrasting thermal imaging and continuous wave laser illumination systems. The next section will describe how each technology is used in the real world.

How to Compare – A Common Framework

In order to effectively evaluate the two technologies, a common framework for comparison must be utilized. Despite some limitations, there is a well-known tool utilized to assess the effectiveness of night-vision systems referred to as the "Johnson's Criteria." Johnson's Criteria is commonly used to understand how well a given night vision system (or any optical system) will perform at certain ranges for certain targets.

John Johnson, a US Army Night Vision Lab scientist in the 1950s, developed methods of predicting target detection, orientation, recognition and identification for evaluating the performance of visual devices such as night vision systems. In fact, Johnson's Criteria led to the emergence of many models for sensor technology which have been used to predict the performance of sensor systems under different environmental and operational conditions.

Definitions of detection, recognition, and identification as outlined by Johnson's Criteria will be used during the remainder of this paper to compare and contrast thermal imaging and continuous wave laser illumination systems.

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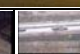
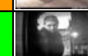
Comparing the Chief Technologies Using the Johnson's Criteria

The table below summarizes several technical aspects of thermal imaging and continuous wave laser illumination. Continuous wave laser illumination technology, represented by Vumii's Discoverii 1000, 2000 and 3000 solutions, clearly reveals that the performance capabilities are superior to thermal imaging in terms of identifying images during the day or at night, particularly at distances greater than 600 meters. The table also highlights how continuous wave laser illumination systems use a continuous zoom, high magnification optical lens for true surveillance assessment capabilities. Conversely, the typical uncooled thermal imaging product has a fixed field of view for a specific range and operates using heat differentials - meaning performance is better at night, not during the day. This table will serve as a guide for several discussion points throughout the remainder of this document.

Performance Capabilities: Thermal Imaging vs. Continuous Wave Laser Illumination (Discoverii)																		
Detection		An object is present: **1.5 to 7** pixels needed																
Recognition		The type of object can be discerned, a person vs. a car: **8 to 10** pixels needed																
Identification		A specific object can be discerned, a woman vs. a man, the specific car: **11 to 15** pixels needed																
System Type		**Uncooled Thermal Imager .25µ pitch**					**Cooled Thermal Imager 14.8 micron X 14.8 micron**						**Discoverii 1000**		**Discoverii 2000**		**Discoverii 3000**	
Video resolution		320 x 240					640 x 480						640 x 480		640 x 480		640 x 480	
Time of Day		Primarily Night					Primarily Night but some use during the day						Day	Night	Day	Night	Day	Night
Horizontal Field of View (FOV)		15°	6°	5°	4°	3°	11°	5.5°	3.6°	2.2°	1.1°	0.7°	2.2°-55°	0.6°-6° (Laser spot)	.54°-11.8°	0.6°-6° (Laser spot)	.18°-21° (X60 zoom+ext)	0.4°-4° (Laser spot)
Lens		30mm	75mm	100mm	150mm	180mm	50mm	100mm	150mm	250mm	500mm	750mm	3.5-91 mm	3.5-91 mm	23-506 mm	23-506 mm	25–1500mm	25–1500mm
Pixels at ranges of	600 meters	3	7.5	9	11.25	15	10	20	30	51	101	152	48	48	144	144	435	435
	1500 meters	< 1.5	3	3.6	4.5	6	4	8	12	20	41	61	19	19	57	57	174	174
	1800 meters	< 1.5	<1.5	3	3.75	5	3	7	10	17	34	51	16	16	48	48	145	145
	2100 meters	< 1.5	< 1.5	< 1.5	3	4	3	6	9	14	5	43	14	< 1.5	41	41	124	124
	3000 meters	< 1.5	< 1.5	< 1.5	< 1.5	3	2	4	6	10	20	30	10	< 1.5	29	29	87	87
	5000 meters	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	2	4	6	12	18	6	< 1.5	17	< 1.5	52	< 1.5
	10000 meters	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	2	3	6	9	3	< 1.5	9	< 1.5	26	< 1.5
Field of View Capabilities		Typical Uncooled Thermal Imagers have a fixed FOV; therefore a separate specialized thermal lens is needed for each range.					Some Cooled thermal imagers have multiple or continuous field of views, but are extremely expensive.						Discoverii systems have continuous zoom, high magnification optical lenses allowing true surveillance assessment capabilities.					
24x7 operation		Thermal imagers operate on heat differentials, so performance is better at night than day and best at dusk and dawn					Cooled thermal imagers perform better during the day than uncooled thermal imagers but not as well as a typical CCD imager.						Discoverii systems operate on near-optical differentials, so performance is consistent day (color) and night (grayscale) by using its own invisible light source. The limiting factor at night is illumination and not magnification.					

*** note: defitions of detection, recognition, and identification are the minimum resolution in pixels according to the Johnson criteria giving a 50% probability of an observer discriminating an object to the specified level.**

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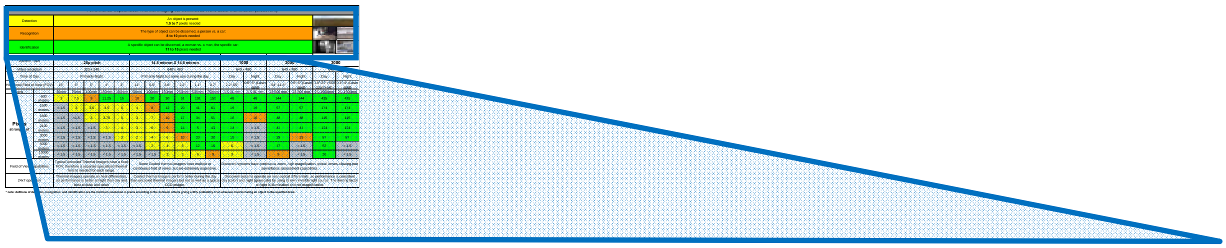
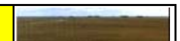
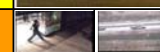
Understanding the Comparison Criteria

This next section of the white paper examines detection, recognition and identification capabilities both in terms of the Johnson's Criteria as well as in real world applications.



Detection	An object is present: **1.5 to 7** pixels needed	
Recognition	The type of object can be discerned, a person vs. a car: **8 to 10** pixels needed	
Identification	A specific object can be discerned, a woman vs. a man, the specific car: **11 to 15** pixels needed	

Detection

The most common metric heard today as it relates to night vision performance is its detection capabilities. Johnson's Criteria is quite lenient relating to what is considered a high enough pixel count to constitute detection. In the example above, only 1.5 to seven pixels are needed in an entire video screen to represent a detected image. However, such detection does not provide much toward understanding what the target actually represents. This is a key consideration when comparing various night vision technology options.

Recognition

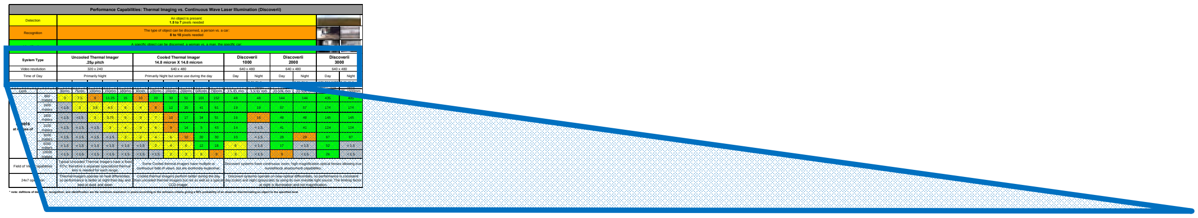
Recognition is defined by whether an object can be discerned and whether the target is a vehicle, person, building or even an animal. According to Johnson's Criteria, eight to 10 pixels are needed to make this determination. Again, this is fairly generous as many industry experts feel far more pixels are required for accurate recognition.

Identification

The last major criterion involves identification. Most thermal imaging companies do not even discuss this aspect of Johnson's Criteria as it is difficult to hit this performance level at long-distance ranges. The Johnson Criteria states that 11 to 15 pixels are required for identification – the ability to discern a specific object such as whether the target is a woman or a man or identifying a specific model of car.

Various Models per Technology

This next section highlights common thermal and continuous wave laser illumination configurations examining specific horizontal fields of view and the types of fixed and zoom lenses found in a variety of solutions.



System Type	Uncooled Thermal Imager .25µ pitch					Cooled Thermal Imager 14.8 micron X 14.8 micron						Discoverii 1000		Discoverii 2000		Discoverii 3000	
Video resolution	320 x 240					640 x 480						640 x 480		640 x 480		640 x 480	
Time of Day	Primarily Night					Primarily Night but some use during the day						Day	Night	Day	Night	Day	Night
Horizontal Field of View (FOV)	15°	6°	5°	4°	3°	11°	5.5°	3.6°	2.2°	1.1°	0.7°	2.2°-55°	0.6°-6° (Laser spot)	.54°-11.8°	0.6°-6° (Laser spot)	.18°-21° (X60 zoom+ext)	0.4°-4° (Laser spot)
Lens	30mm	75mm	100mm	150mm	180mm	50mm	100mm	150mm	250mm	500mm	750mm	3.5-91 mm	3.5-91 mm	23-506 mm	23-506 mm	25–1500mm	25–1500mm

Thermal Imager Systems

Typically, thermal systems do not come with zoomable lenses. Usually, there is only a single focal length represented by one fixed lens. Therefore, one commonly will see thermal imagers defined by their horizontal field of view. In the chart above, some common fields of view include 15°, 6°, 5°, 4°, and 3° with associated focal lengths of 30 mm, 75 mm, 100 mm, 150 mm, and 180 mm, respectively. The further the range of the thermal imager, the more narrow the field of view. Some thermal imagers can be paired with a continuous wave laser illumination system for detection only. But the field of view of such thermal imagers must be narrowed to a smaller horizontal degree in order to reach the same detection range of the identification/recognition range of a continuous wave laser illumination system. Multiple fixed lenses can be added to a thermal system but this adds exponentially to its costs as there are physical lens changes required for each horizontal field of view.

Continuous Wave Laser Illumination Systems

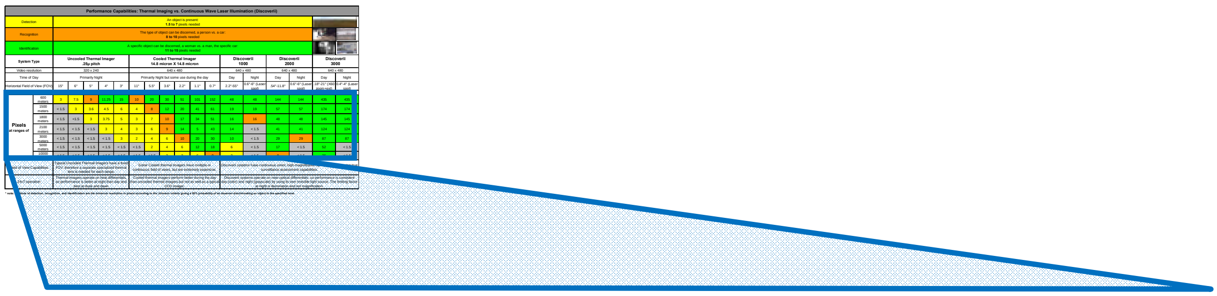
Continuous wave laser illumination systems require only a single zoomable lens to cover what is possible by combining several thermal imaging systems. To date, Vumii's Discoverii system is the only product to utilize a fully zoomable continuous wave laser illumination solution. Vumii holds several provisional patents related to this technology. Currently there are three models utilizing continuous wave laser illumination - the Discoverii 1000, Discoverii 2000, and the Discoverii 3000. The 1000/2000/3000 designations are a general indicator of range in meters. When compared to the Johnson Criteria, all of these models easily meet all of the related performance metrics demonstrating that each model could outperform its range designation. For each model, there are different zoom capabilities as detailed in the chart above. In addition, the horizontal field of view is different at night time than during the day since the laser beam diameter is typically narrower than the video image produced by the camera, especially at wider zoom levels.

Shared Features of the Configurations

Often thermal and continuous wave laser illumination systems are driven by mechanical pan-tilt units and are environmentally sound in severe weather conditions. For the purpose of this white paper, this particular feature is assumed to be equal when examining the two technologies.

Performance Difference at Various Ranges

This next section looks at the how each technology performs within a set of given ranges.



Pixels at ranges of	600 meters	3	7.5	9	11.25	15	10	20	30	51	101	152	48	48	144	144	435	435
	1500 meters	< 1.5	3	3.6	4.5	6	4	8	12	20	41	61	19	19	57	57	174	174
	1800 meters	< 1.5	<1.5	3	3.75	5	3	7	10	17	34	51	16	16	48	48	145	145
	2100 meters	< 1.5	< 1.5	< 1.5	3	4	3	6	9	14	5	43	14	< 1.5	41	41	124	124
	3000 meters	< 1.5	< 1.5	< 1.5	< 1.5	3	2	4	6	10	20	30	10	< 1.5	29	29	87	87
	5000 meters	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	2	4	6	12	18	6	< 1.5	17	< 1.5	52	< 1.5
	10000 meters	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	2	3	6	9	3	< 1.5	9	< 1.5	26	< 1.5

Thermal Imager Systems

Generally speaking, the above chart shows that thermal imaging systems are more suited for detection at ranges of less than 1000 meters. Some systems perform better but utilize a far smaller field of view. As an example, the 3° thermal imager can identify targets at 600 meters and detect them between 1500 and 3000 meters. However, what is gained by having a better range is lost by having a very narrow field of view. In contrast, the 15° thermal imaging system has a superb field of view to see several activities at once but at the expense of a relatively short range such as 600 meters or less.

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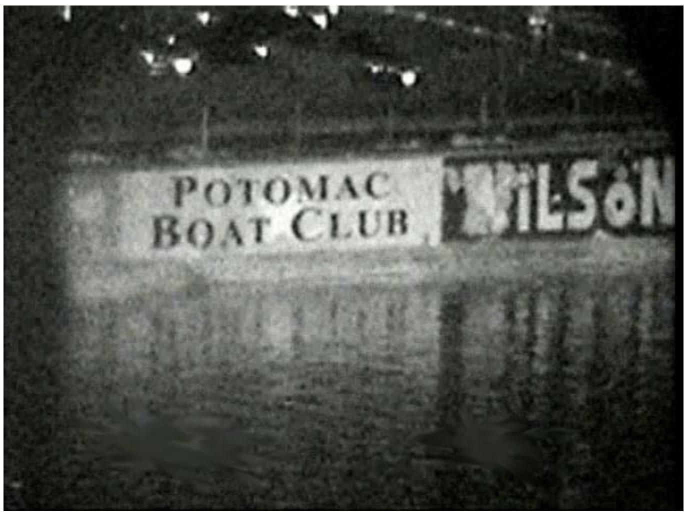
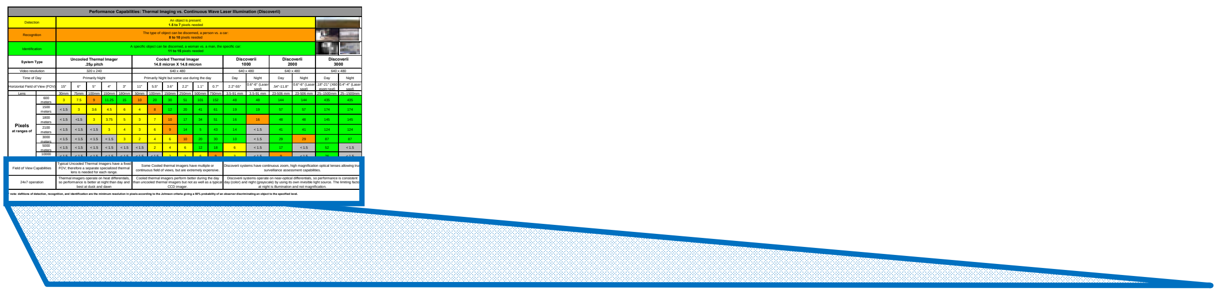
Continuous Wave Laser Illumination Systems

Vumii's line of Discoverii continuous wave laser illumination systems are able to identify targets at all ranges between 600 and 3000 meters. This is achieved in several ways. Since there is a zoomable lens, the systems are able to zoom appropriately to identify a target depending on the distance of the target. In addition, the video resolution of all Discoverii systems is much higher than typical thermal systems. Specifically, the Discoverii systems have a video resolution of 640 x 480 pixels while most commercial off-the-shelf thermal imaging systems only have a video resolution of 320 x 240 pixels. Because a Discoverii system uses active illumination, it can easily pick up any type of target instead of relying on heat emitted by the target. As shown in the above table, the pixel counts for each given range are far superior for the Discoverii systems compared to the thermal imaging systems.



Key Benefits of Continuous Wave Laser Illumination over Thermal Imaging

The following segment describes key advantages of the continuous wave laser illumination systems over thermal imagers including higher resolution.



Field of View Capabilities	Typical Uncooled Thermal Imagers have a fixed FOV; therefore a separate specialized thermal lens is needed for each range.	Some Cooled thermal imagers have multiple or continuous field of views, but are extremely expensive.	Discoverii systems have continuous zoom, high magnification optical lenses allowing true surveillance assessment capabilities.
24x7 operation	Thermal imagers operate on heat differentials, so performance is better at night than day and best at dusk and dawn	Cooled thermal imagers perform better during the day than uncooled thermal imagers but not as well as a typical CCD imager.	Discoverii systems operate on near-optical differentials, so performance is consistent day (color) and night (grayscale) by using its own invisible light source. The limiting factor at night is illumination and not magnification.

Key benefits contributing to the superiority of continuous wave laser illumination systems such as Discoverii include but aren't limited to improved pixel performance:

- Most thermal imagers are lower resolution 320 x 240 arrays. Discoverii provides a 640 x 480 standard PAL or NTSC video image day or night. Discoverii can be scaled to higher resolution megapixel cameras contingent upon their sensitivity to the laser spectrum used. Thermal imaging arrays are much more difficult to scale to megapixel and unlikely to occur or be cost efficient in the next five years.
- Continuous wave laser illumination systems offer a natural contrast image compared to heat-contrast images. This means that Discoverii provides images in which people look like people and words, characters, and markings can be read. In thermal technology, people look like blobs and text cannot be seen since the text is often the same temperature as the surface on which it is written. Many "friendly fire" incidents that occur in world-wide military exercises are the result of thermal imagery's inability to provide real recognition and identification capabilities.

In addition, regardless of pixel performance there are other important key benefits of continuous wave laser illumination vs. thermal imaging.

- Thermal systems typically utilize specialized imager components and fixed focal length lenses, meaning magnification cannot be changed once a lens is chosen. In theory, thermal imaging systems can incorporate high magnification fixed lenses or even variable magnification lenses. However, these are made of Germanium and are quite expensive and fragile as such applications are not commercially practical or viable. Continuous wave laser illumination systems such as Discoverii use continuous optical zoom capabilities. In fact, both the laser light source and the imager automatically zoom at the same time, providing efficient light only on the object where the camera is aimed. Continuous zoom is incredibly important for security assessment since subjects are often moving and at different ranges from camera systems.

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- Due to the natural contrast image quality and image resolution, human recognition and identification is possible with Discoverii, while virtually impossible with thermal technologies. This also means unlike thermal images, continuous wave laser illumination system video can be submitted in a court of law as evidence.
- Heat contrasts change throughout the day and night yielding very different images for thermal-based systems depending upon the time. Thermal contrasts are very poor at the end of night since most objects have become the same temperature as the ambient temperature. Continuous wave laser illumination technology uses sunlight in the daytime and its own highly controlled light source (a CW invisible laser) at night. This produces consistent grayscale/normal looking imagery at night and full color imagery during the day. Often, separate daytime systems must be purchased to complement thermal-based systems.
- Continuous wave laser illumination systems can be dynamically controlled by the user. The beam divergence can be widened or narrowed and the light intensity can be increased or decreased with software or joystick controls. This enables the most versatile user-controlled lighting to enable such tasks as reading reflective numbers on vessels or license plates on vehicles.
- Continuous wave laser illumination systems don’t use an image intensifying CCD and ignore almost all visible light at night. This means that direct light doesn’t negatively impact images by oversaturation (“blooming”) that is common with thermal systems.
- To thermal imagers, glass is a visual barrier since it does not transmit heat very well, if at all. Continuous wave laser illumination technology sees through glass windows and vehicle windshields since it has its own dynamically directional light source.
- Due to the natural contrast imagery and continuous zoom optics, users of continuous wave laser illumination systems require very little training and incur no eye irritation. Users of thermal technologies experience constant eye irritation and require considerable training to determine what is being seen.
- Other than low resolution simple optics thermal-based systems, continuous wave laser illumination systems are generally less expensive than competing thermal technologies.

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History of Thermal Imaging and Continuous Wave Laser Illumination

Thermal Imaging

Thermal Imaging dates back to 1800 when Sir William Herschel, an astronomer who also discovered Uranus, uncovered the properties of infrared light. After creating his own telescopes and becoming well versed in the use of lenses, mirrors, and light refraction, he began to research thermography. Hershel knew that sunlight was composed of all colors of the spectrum and a source of heat, so he had a goal to determine which colors were responsible for heating objects.[iv] Ultimately, this research was used by the military to develop technology that would help them see and target opposing forces through the night and also across smoke-covered battlegrounds.

In the late 1950s and early 1960s, single element detectors that scanned scenes and produced line images were developed by Honeywell, Hughes Aircraft, and Texas Instruments. These advances led to the development of thermal imaging. Previously, though, the military had a lock on the technology due to expense and sensitive military applications. [iv]

In 1978, the technology progressed further when Raytheon's research and development group patented ferroelectric infrared detectors that were first demonstrated to the military in 1979. In the late 1980s, the federal government awarded contracts to both Raytheon and Honeywell for the development of thermal imaging for more practical military applications. Throughout the decades, the core physics of this technology has not changed. Thermal imaging is used in firefighting, law enforcement, industrial applications, security, transportation, and many other industries.

Continuous Wave Laser Illumination

Continuous Wave Laser Illumination was prefaced by range-gated laser technology, which was invented by Dr. Miky Tamir, a highly accomplished technology veteran and entrepreneur specializing in advanced electro-optical, image processing and 3D graphics technologies for the security, defense and broadcast markets. Range-gated technology completely changed the way people saw in little to zero light and it operates on an entirely different concept from thermal imagery. In range-gated technology, a laser is pulsed, and it will output a burst of light for less than a millionth of a second. A timer is used and turns on an imager only when light from a certain distance is returned to a camera. This process allows the user to see things that reflected light at that distance and only from that distance.

Continuous wave laser illumination was revolutionized in 2005 when Tamir realized that there was a more efficient way of achieving better results than range-gated laser technology provided. Continuous wave lasers are far less complex, and have less expensive subassemblies, which provides for a lower lifetime cost (TCO). Vumii produced the first production continuous wave laser illumination device in March 2006.

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Conclusion

Based on scalability, magnification, pixel performance, zoom capabilities, versatility, maintenance, and controllable light sources, continuous wave laser illumination offers numerous distinct benefits over thermal imaging.

The weaknesses of thermal imaging solutions for long-range, high-magnification applications demonstrate that continuous wave laser illumination is better suited for helping security professionals identify targets, recognize facial features and read license plates and ship identification numbers at distances up to 3000 meters.

Continuous wave laser illumination systems provide better long-range visibility to any type of target while using conventional thermal technology for distances greater than several hundred meters may actually hinder the ability to view potential security threats.

About Vumii

Vumii develops and delivers advanced night vision surveillance and graphical user control systems which enable users to prevent and rapidly respond to terrorism, theft, vandalism, asset damage and other physical security threats. Vumii leverages advanced electro-optics and image processing expertise to create high performance, versatile, visualization hardware and software technologies for the defense and physical security markets. Vumii solutions are affordable and easily integrate with existing security architectures. Founded in 2004, Vumii is a privately-held company headquartered in Atlanta, GA US. For more information, visit www.vumii.com.

[i] About.com: Inventors
[ii] Wikipedia
[iii] http://www.morovision.com/how_thermal_imaging_works.htm
[iv] About.com

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