Overview of the UL3 Omega™ uncooled camera and its applications

Joseph Kostrzewa, William Meyer, Doug Kraemer,
George Poe, Vu Nguyen, Mark Brown, William Terre
Indigo Systems Corporation, Santa Barbara, CA 93111

Gwendolyn Newsome
U.S. Army Night Vision and Electronic Sensors Directorate
10221 Burbeck Rd., Fort Belvoir, VA 22060-5806

ABSTRACT

When it was first introduced two years ago, Indigo Systems Corporation's UL3 Alpha™, a miniature uncooled infrared camera, set new standards for ultra-low size, weight and power within the thermal imaging industry. Now Omega™, the next generation in Indigo's UL3 product line, takes advantage of novel algorithms and packaging concepts to further reduce size, weight, and power while still improving performance. These qualities make Omega™ an ideal candidate for many commercial and military applications, including fire-fighting, law enforcement, industrial inspection, remote surveillance, miniature unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGV), and numerous other possibilities. This paper describes the design, performance and salient features of the Omega™ camera. Current and future applications of the UL3 product line are also discussed.

Keywords: uncooled, infrared, low cost, miniature, microbolometer, TEC-less

1. INTRODUCTION

With the proliferation of uncooled infrared sensors in the past decade, thermal cameras are finding utility in many new and exciting applications. Military applications include weapon-sights, payloads for miniature UAVs and UGVs, fixed-emplacement sensors for surveillance and security, and sensors strapped to soldiers arms, helmets, or other equipment to improve their stealth and mobility in darkness. In the commercial sector, hand-held (and hands-free) sensors for firefighting, law-enforcement, and predictive maintenance are becoming increasingly common. All of these applications demand portability (i.e. small size and light weight) and the ability to operate for long periods of time from a battery (i.e. low power consumption). Affordability is yet another fundamental requirement. Indigo systems has developed innovative technology that has enabled a new category of infrared sensor: the low-cost microsensor.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**
4. TITLE AND SUBTITLE **Overview of the UL3 Omega (TM) uncooled camera and its applications**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army Night Vision and Electronic Sensors Directorate,10221 Burbeck Road,Fort Belvoir,VA,22060-5806**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**7**	

Indigo Systems is a pioneer in the miniature IR camera market, having begun development of its UL3 product line in 1997. The name UL3 stands for Ultra-Low Size, Ultra-Lightweight, and Ultra-Low Power. Aspects of Indigo's UL3 camera development were partially funded by the U.S. Army Night Vision Electronic Sensors Directorate (NVESD). The first UL3 product introduced was the Alpha™ camera, which went into full-scale production in 1999. At that time, Alpha™ was the world's smallest, lightest, lowest-power infrared camera commercially available. Now its successor, the Omega™, improves on every aspect of the original design. Power consumption has been reduced by nearly 30% (from 1.5W to 1.1W), weight by 45% (from 186g to 102g), volume by 60% (from 8.7 in^3 to 3.5 in^3), and NEdT has improved by approximately 20%. Furthermore, Omega™ is designed for high-volume manufacturing, making it economically viable for proliferation markets. Figure 1 shows the two cameras side-by-side, and Table 1 compares specifications.

Figure 1: Alpha™ and Omega™. *Omega™ is significantly smaller and lighter than its predecessor.*

Table 1: Alpha™ and Omega™ specifications

	Alpha™	Omega™
Weight (w/ 18 mm lens)	186 g	102 g
Dimensions (w/out lens)	1.7" x 1.7" x 3.0"	1.4" x 1.3" x 1.9"
Volume	8.7 in^3	3.5 in^3
Power Consumption	≤1500 mW (room temp.) ≤2500 mW (extreme temp.)	≤1100 mW
Array size	164 x 129	164 x 129
NEdT at f/1.6	≤ 100 mK	≤ 85 mK
Temp. Range	0°C to +55°C	-40°C to +55°C

2. TEC-LESS OPERATION

One of the main drivers of Omega's™ improved performance relative to Alpha™ is the lack of a Thermoelectric Cooler (TEC). Like most uncooled cameras, Alpha™ uses a TEC to hold the focal plane array (FPA) at a stable temperature. Temperature stabilization is required because output of the array would otherwise vary radically and non-uniformly, causing undesirable image artifacts. Conversely, Omega™ employs a novel combination of on-focal-plane circuitry and non-uniformity correction (NUC) processing to eliminate the TEC. The unique approach to TEC-less operation, which is currently patent-pending, enables the camera to operate over a wide temperature range while maintaining excellent dynamic range and image uniformity. Figure 2 demonstrates the ability of the camera to hold a very stable spatial-noise floor over a 40-degree span.

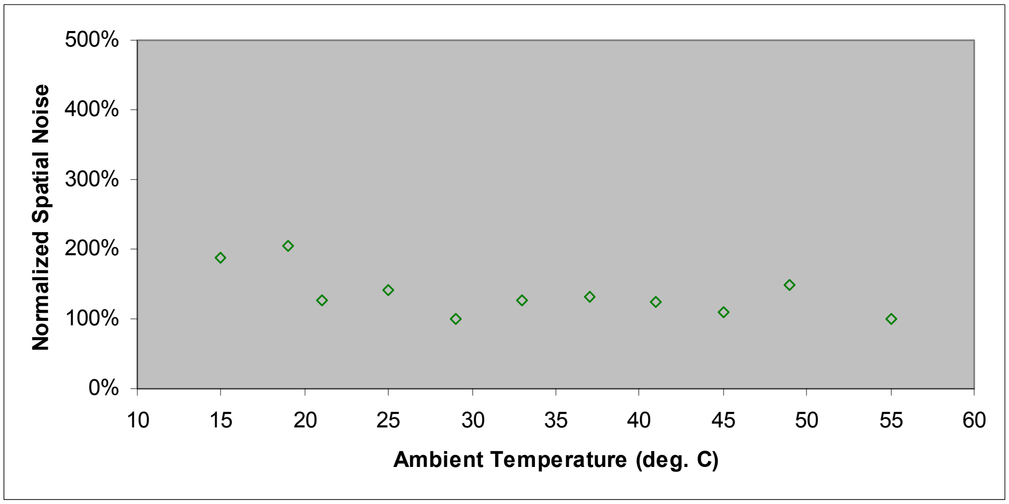


Figure 2: Spatial noise vs. ambient temperature. *A novel algorithm for TEC-less operation maintains excellent uniformity over a very wide temperature range.*

An obvious advantage of TEC-less operation is the savings in cost, size, and power associated with a TEC. A second benefit of eliminating the TEC is that the system can begin imaging almost immediately after turn-on rather than waiting for FPA temperature to stabilize. A less obvious attribute of TEC-less operation is the potential for the camera to operate over a wider temperature range. If the FPA is held at constant temperature, then as the difference between the TEC setpoint and ambient temperature grows, the power consumption of the TEC increases as well as the magnitude of out-of-field irradiance. As shown in Figure 3, the solid angle subtended by out-of-field sources (such as the vacuum package and optical housing) is 10 times greater than the in-field angle for an f/1.6 system. Consequently, a 1-degree temperature difference between the FPA and out-of-field sources consumes as much dynamic range as a 10-degree difference between the FPA and the imaged scene. This issue limits the operating temperature range of a system that holds the FPA temperature constant. Conversely, the FPA and out-of-field sources are always at approximately the same temperature when there is no TEC, and thus there is no dynamic range penalty from operating over a wide ambient temperature range.

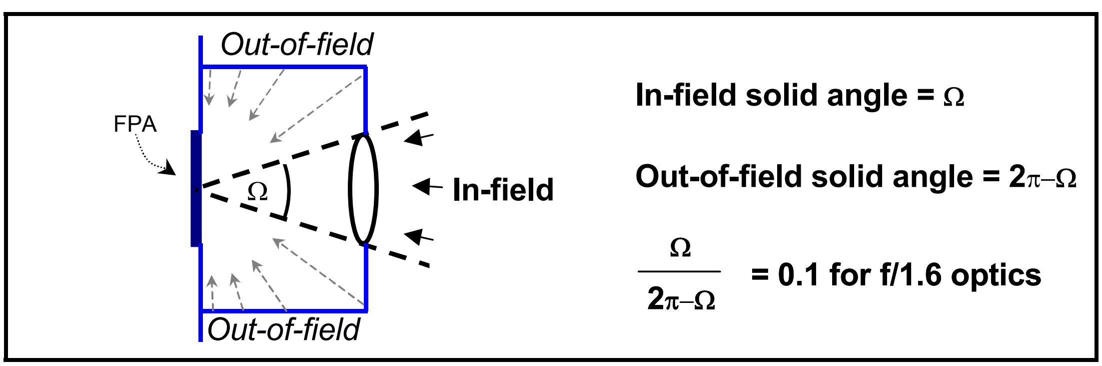


Figure 3: In-field vs. out-of-field solid angle. *For f/1.6 optics, a 10°C difference between the detector and out-of-field sources is equivalent to a 100°C difference between the detector and in-field scene. Eliminating a TEC vastly reduces the out-of-field signal by allowing the FPA and out-of-field sources to be at thermal equilibrium.*

3. INTERCHANGEABLE LENSES

By optimizing the readout integrated circuit (ROIC) and microbolometer designs for high sensitivity, Omega™ is capable of providing excellent sensitivity while using slower, more compact optical designs than those typically found on uncooled thermal sensors. Like Alpha™, Omega™ is available with a choice of f/1.6 lens assemblies. Unlike Alpha™ however, Omega™ provides the option of swapping lenses in the field; this is because the camera has sufficient memory to store factory-calibration terms for up to 3 different configurations. Figure 4 shows the three standard f/1.6 lenses currently available, and Table 2 lists their significant specifications. Each of these assemblies is manually focused, and focus position can be locked with a set screw. Indigo also plans to offer an f/1 lens option for applications that demand very high sensitivity as well as a 9-mm focal-length option for wide field-of-view applications.

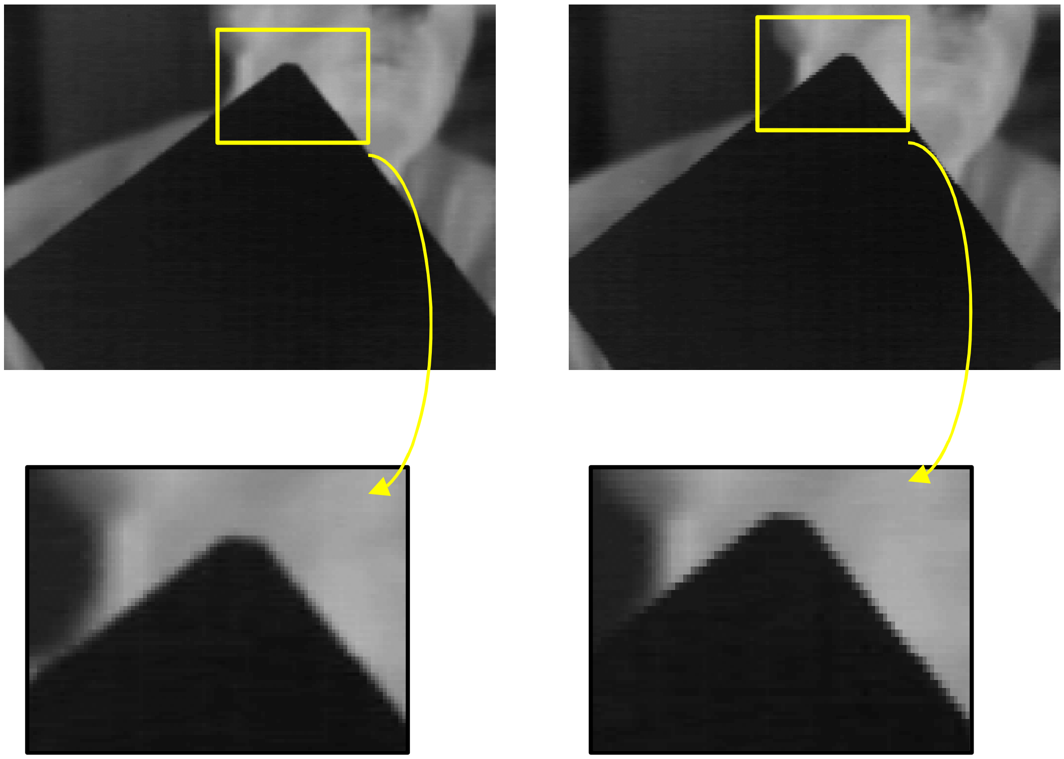
Figure 4: Three standard f/1.6 lens options. *Omega™ lenses are interchangeable in the field.*

Table 1: Specifications for the f/1.6 lenses.

Focal length	**11 mm**	**18 mm**	**30 mm**
FOV	40°x30°	25°x19°	15°x11°
f/#	f/1.6	f/1.6	f/1.6
Min. focus	0.1 m	0.3 m	0.3 m
Length	1.1”	0.9”	1.4”
Weight	33 g	26 g	38 g

4. VIDEO PROCESSING

Omega™ supplies both a 14-bit digital output and an analog video output (RS170a or CCIR). Standard video processing features are provided, including automatic dynamic image optimization, polarity control (white-hot / black-hot), image-orientation control (i.e. invert / revert), on-screen symbols, and freeze-frame capability. Also, the camera automatically transitions between a low-sensitivity mode (with a maximum scene temperature of 400°C) and a high-sensitivity mode (150°C maximum) based on scene content. The video is expanded from small-format (160x120) to mid-format (320x240) using bilinear interpolation. This smoothing operation eliminates the perception of pixelation, and the resulting imagery is more pleasing to the human eye. The snapshots in Figure 5 exemplify the image enhancement provided by the smoothing algorithm.



(a) smoothing (b) no smoothing

Figure 5: Omega™ images with and without smoothing. *Bilinear interpolation reduces pixelation in Omega™ imagery*.

5. APPLICATIONS

One of the large near-term markets for Omega™ is anticipated to be the firefighting industry. Omega™ is the first camera that is sufficiently small to enable helmet-mounted and other hands-free options for firefighters. The resulting product is a compact thermal imager that enables firefighters to navigate and search through smoke and darkness without sacrificing mobility or dexterity. Another commercial application for Omega™ is predictive maintenance. Indigo is supplying a radiometric configuration of the camera as the sensor engine for a handheld radiometer intended for thermography. Unlike many other radiometers, Omega™ does not require a radiation shield since the FPA temperature floats with the rest of the camera case. Impressive radiometric accuracy is therefore maintained without the radiation shield. A potential application of Omega in its baseline configuration is for border patrol and public safety. Monitoring high-value assets such as airport perimeters, pipelines, water reservoirs, and nuclear reactors substantially reduces the risk of sabotage or tampering. The use of thermal imagery allows around-the-clock and adverse-weather capability over conventional video systems, and its small size and high sensitivity make Omega™ an ideal surveillance camera. Indigo is also developing a complete imaging system based on Omega™ that includes an integral display and battery; this standalone device is suitable for many applications including law-enforcement.

6. THE FUTURE OF UL3

Despite its name, Omega™ is not the finale of the UL3 microcamera product line. Because the system architecture is highly flexible, it can be easily adapted to accommodate different FPAs. In fact, as shown in Figure 6, Omega™ is the basis for two other UL3 products currently in development. The first in a Near Infrared (NIR) spin-off that employs a mid-format InGaAs array. The NIR camera, which is sensitive from 900 to 1700 nm, is ideally suited for detection of telecommunication laser radiation, particularly in the S, C, and L DWDM wavebands. Uses include laser beam profiling, silicon wafer characterization, fiber alignment and inspection, and optical component measurement and analysis. The second Omega™-based product that is currently in development is an upgrade employing a mid-format (320x240) microbolometer array. The mid-format upgrade is appropriate for any application that demands more resolution than that provided by Omega™.

The Omega™ mechanical design will accommodate Indigo's ISC9809 (320x240 InGaAs) and ISC9908 (320x240 microbolometer) vacuum packages without any growth in camera volume. Furthermore, the camera's signal processing electronics are extremely adaptable; in fact, only software modifications will be required to transition to the NIR product. As a result, the NIR spin-off will look very similar to Omega™ other than the fact that it will use glass optics rather than germanium. Similarly, the mid-format microbolometer array will be only slightly larger than the small-format Omega™ camera.

Figure 6: UL3 product line. *The Omega™ is the basis for a NIR product and a mid-format microbolometer upgrade.*

7. SUMMARY

Indigo System's Alpha™ was once the world's smallest, lightest, lowest-powered infrared camera. Now Alpha™ has been surpassed by Omega™, which improves on every aspect of the original design. The UL3 Omega™ weighs merely 102 grams, consumes less than 1100 mW, and occupies only 3.5 cubic inches. The camera operates without a TEC, providing excellent uniformity and dynamic range across a wide operating temperature range (-40°C to +55°C). Omega™ is ideally suited for a host of applications that demand portability and long battery life. Commercial markets include firefighting, thermography, and public safety.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of U.S. Army CECOM, Night Vision & Electronic Sensors Directorate, Ft. Belvoir Virginia.