Application Note

Advanced IR Optical Assemblies for UAVs and Drones

Meeting SWaP constraints

mks | Ophir®

PROBLEM The UAV industry has significantly evolved and grown in recent years. Alongside this growth, we have seen the development of UAVs and drones with increasingly advanced infrared imaging systems, containing detectors that are larger in size and smaller in pixel size, which present challenges for UAV optics.

Lens quality must increase in order to maximize imaging performance in line with detector capabilities, allowing for high resolution vision. Three crucial factors should always be considered to ensure the optical assembly is suitable for UAVs and drones, these are known as SWaP - Size, Weight, and Power consumption. In other words, the optics must be compact, lightweight, and with reduced power consumption, in order to enable maximum flight time.

The challenge falls on optical manufacturers to design and produce optics with a crisp, clean image over the entire zoom range, and an MTF close to the diffraction limit, while meeting strict SWaP requirements. Optics must also be able to withstand the harsh environmental conditions associated with various UAV and drone applications, such as in the defense industry.

BACKGROUND The unmanned aerial vehicle (UAV) industry is growing rapidly, with Teal Group analysts estimating that worldwide UAV production will total $135 billion in the next ten years[1]. When equipped with high performance EO/IR camera payloads, UAVs and drones, lend themselves to a wide range of imaging applications.

The drone market consists of defense, government, and commercial applications. In the area of defense and government, drones are used for military and police surveillance, border control, security, and search and rescue operations. Between 2009 and early 2017, at least 347 law enforcement and emergency responder agencies in the U.S. acquired drones[2].

Fig.1: Unmanned Aerial Vehicle (UAV) with compact gimble payload

In the commercial drone market, demands have been growing. Commercial drones with thermal imaging capabilities are playing a prominent role in inspecting electrical power lines, oil pipelines, forest fire detection, and other infrastructures. Such capabilities are also used to assist in firefighting operations, locating and assessing fires, even when visibility is poor.

As UAV technology is applied in an increasing variety of sophisticated tasks, we see a growing need to maximize imaging performance. Specific optical needs are presented by the aforementioned increase in detector resolution and size, with its accompanying decrease in pixel size.

The production of smaller drones for commercial use also increases the challenges faced by optical manufacturers.

SOLUTION High quality lenses are essential to leverage the advances in detector performance. An inferior lens will produce an inferior image, even with the best detector. In order to match high performance, small pixel detectors, lower F#s, and tighter tolerances are required, forming lenses with minimal aberrations. To answer these requirements, lenses must also have a long focal length, to capture images from large distances. Our solution is based on advanced folded-optics and lightweight zoom lenses, optimized for the next generation infrared thermal imaging systems.

Lenses for UAVs and Drones

Ophir utilizes various state-of-the-art technologies to meet UAV and drone optical requirements. These technological solutions include innovative optical and mechanical designs, exotic materials, and unique lens manufacturing and coatings technologies.

Continuous zoom lenses address the low-SWaP challenge while keeping high optical performance. These lenses are smaller and lighter than using multiple 1-FOV lenses. In addition, a continuous zoom lens enables better mission flexibility by allowing changes in magnification during a UAV operation.

Working in collaboration with defense and commercial customers, Ophir has developed a range of thermal imaging zoom lenses that are both lightweight and high-performance, designed specifically for use in UAV payloads, drones, and hand-held devices. The advanced zoom lenses use a sophisticated optomechanical design, to ensure that the lenses are the smallest, lightest, and most compact, while still achieving the highest levels of IR thermal imaging performance.

For example, Figure 2(a) shows the LightIR 20-275mm f/5.5 lightweight zoom lens, and its opto-mechanical layout. The innovative opto-mechanical design resulted in a weight of only 264 grams. Despite the challenging SWaP restrictions, the advanced lightweight design resulted in high level of MTF values across the entire field, as shown in Figure 3(b). Moreover, the selection of advanced materials enabled unique athermalization properties, maintaining the highest performance over a wide operating temperatures, in the range of -35°C to +65°C.

The characteristics of this lens lead to long operational ranges relative to the lens size and weight. For example, the detection range of a 2.3m vehicle would be around 15km(!) when integrated with a 23mK NETD, 15μm pixel detector (based on FLIR92 model calculations). To the best of our knowledge, this is the smallest and lightest continuous zoom lens on the market today, enabling the high-performance capabilities of advanced IR thermal imaging systems in harsh environmental conditions and on constrained platforms.

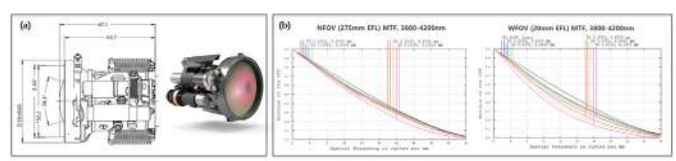

Fig. 2. Lightweight 20-275mm f/5.5 zoom lens
(a) Opto-mechanical layout and picture, (b) MTF characteristics

Another approach to address the low SWaP challenge includes folded-optics configurations that are designed especially for compact gimbaled payloads. An example of this is Ophir's folded-optic 16-180mm f/3.6 zoom lens, optimized for MWIR 10μm pixel detectors.

Figure 3(a) demonstrates the opto-mechanical layout and picture of the 16-180mm f/3.6 zoom lens. The design is based on a standard relay and objective configuration, with two moving groups that allow for the change in the focal length.

The materials were selected using best practices, as well as the athermalization and achromatization concepts.

The folded-optic design enables long optical lengths for reduced sensitivity to tolerances, in a compact configuration, with a reduced number of optical elements, while addressing the various challenges of such a concept. These include line-of-sight (LOS) stabilization, and a reduced number of optical elements, based our capabilities for producing aspheric and diffractive surfaces with exceptional levels of accuracy and quality.

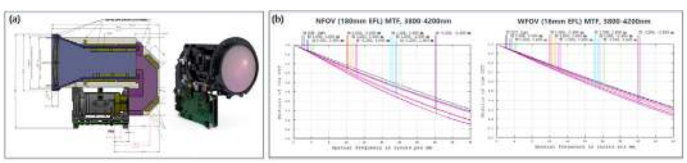

Fig. 3. Folded-optic 16-180mm f/3.6 zoom lens
(a) Opto-mechanical layout and picture, (b) MTF characteristics

Figure 3(b) shows the MTF results as a function of spatial frequency of the 16-180mm folded design for the WFOV and NFOV, illustrating the capabilities of the design to obtain near diffraction limit performance. As can be seen, the high MTF performance of this design is maintained across the entire field and, even at the corners, the performance is more than reasonable.

Diamond turning technology is often used to produce aspheric and diffractive surfaces, with exceptional levels of accuracy and quality. Aspheric lens surfaces are desirable, particularly when it comes to infrared optics, showing significant increases in optical performance over their spherical counterparts. Aspheric-Diffractive lens surfaces allow for the integration of multiple functions, such as chromatic and spherical aberration corrections. Lenses produced by diamond turning can therefore combine multiple elements, reducing overall size and weight.

The use of durable, anti-reflective lens coatings also improves the optical performance, without any impact on the size or weight of the lens. Lens coatings maximize transmission by reducing reflection losses. Advanced coating techniques can be used to produce tailor-made coatings. These coatings can be designed to meet the needs of the UAV industry, where drones may be deployed in a variety of environments, each presenting its own optical challenges.

Product Capabilities

When it comes to optics for UAVs, payloads, drones, and handheld device applications, Ophir's range of products features the following capabilities:

- Small form factor lenses to fit miniature gimbals
- Ultra-light weight zoom & fixed focus lenses
- High optical performance
- Low power consumption
- High durability (HD) or low reflection hard carbon (LRHC) AR coatings
- Fast FOV change
- Continuous zoom, with fixed F# maintained through the full zoom range
- Accurate thru-zoom bore sight
- Compatible with major MWIR & LWIR detectors
- Diffraction-limited optical design

CONCLUSION Advanced optical solutions are the key to airborne mission performance, for guaranteed high imaging quality, without a heavy toll on the UAV payload. UAVs and drones equipped with the ultimate detectors, image processing software, and monitors must also be equipped with a high-performance lens, otherwise risking poor image quality.

Optics for UAVs and drones must meet the strict constraints known as 'SWaP' (Size, Weight, and Power consumption). Meeting these constraints presents challenges to optical lens manufacturers, who must deliver compact, lightweight, and high-performance lenses to operate under harsh environmental conditions.

These constrains are met using cutting-edge manufacturing technologies, and unique opto-mechanical designs. Ophir has successfully designed and implemented advanced IR zoom lenses with reduced SWaP based on a unique folded-optic design, suitable for 10µm pixel size, as well as lightweight opto-mechanical concepts with relatively long focal lengths. In both lenses, we have demonstrated MTF performance close to the diffraction limit, and capabilities for long range, high-resolution vision and identification in harsh environmental conditions, and on constrained platforms.

Such advanced IR optical assemblies meet the challenging UAV industry requirements and open-up new opportunities in next generation UAV and drone thermal imaging application.

REFERENCES

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