Compact Dual Field-of-View Telescope for Small Satellite Payloads

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Introduction & Overview

- Small satellite payloads with multiple FOVs commonly sought
  - Wide FOV to search or scan a scene (Peripheral Vision)
  - Narrow FOV to interrogate and identify an object (Foveated Vision)
- Zoom lenses and multi-sensor approaches are typically too large and massive for Small-Sat payload volumes
- SDL developed a compact, dual FOV telescope for a small unmanned aerial vehicle (UAV) application (patent pending)
  - LWIR spectral band
  - 6x field ratio (between the wide and narrow fields-of-view (FOV))
  - First generation tested in lab and on roof; Second generation designed
  - Concept may be extended to Small-Sat applications for any waveband of interest
Topics

- Compact LWIR dual-FOV Telescope for UAV
- Comparison to zoom lenses and dual FOV sensors
- Conceptual design considerations
  - Design variations on the SDL concept
  - Athermal design considerations
  - Spectral waveband selection considerations
- Fabrication & alignment of dual FOV telescope
- Performance testing
- Modified dual-FOV LWIR telescope
- Compact dual-FOV concept for small satellites
- Summary / conclusion
SDL Compact LWIR Dual-FOV Telescope

- Dual FOV telescope fits within 9 inch ball; shares space with visible sensor
- Catadioptric telescope with two optical (wide/narrow FOV) paths
- Wide and narrow FOVs are split spectrally
  - FOV selected by spectral filter
  - One FOV seen at a time
  - Field ratio of 6 (12 deg / 2 deg)
Comparison to Available Zoom Lens and Dual FOV Sensors

- Available zoom lenses or multiple FOV lenses are compared
- Graph shows the maximum focal length of each lens versus its physical length
  - The SDL dual FOV telescope (narrow FOV) - red square
  - Zoom lens length is generally proportional with its maximum focal length
  - Other spectral regions will show similar trends

Focal length versus physical Length of LWIR dual-FOV and zoom lenses
Comparison to Available Zoom Lens and Dual FOV Sensors (Cont)

- Weight vs. zoom-ratio or FOV-step-ratio comparison
- Graph shows survey results
  - The SDL dual FOV telescope - red square
    - Compares favorably to the lightest available lenses
    - Doubles the zoom of lenses with equivalent mass

Zoom-ratio or FOV-step-ratio vs. lens weight of LWIR dual-FOV zoom lenses
Variations on SDL Design

- Design variations exist for the SDL compact dual FOV telescope:
  - Multiple mirror configuration maximizes the independence of the 2 paths
  - Variations eliminating filter wheel mechanism
    - Use of a two-color FPA
    - Addition of a dichroic beam-splitter ahead of the FPA
- Each variation has its own challenges but may be considered for specific applications and set of requirements
Athermal Design Considerations

- UAVs may experience wide operational temperatures
- Telescope must stay in focus (athermal) over wide ambient temperatures
- First generation design achieved athermal performance over -25 C to +40 C without heaters or active focus adjustment
  - Strategic selection of refractive materials
  - Sequence of refractive materials
  - Balance dn/dT (refractive elements) with dL/dT (aluminum mirrors)
- Second generation design requires heaters (traded reduction in athermal range for an increase in throughput)
Spectral Waveband Selection Considerations

- SDL compact dual-FOV telescope was designed for the LWIR region
- Concept may be extended to any spectral region of interest: ultra-violet (UV) through the LWIR
- Design considerations for other spectral regions:
  - Selection of refractive element materials in the optics
  - Selection of an appropriate focal plane array (FPA)
  - Spectral radiometric parameters for the mission of interest
- Working through these issues is a core-competency of SDL
The compact UAV telescope was fabricated and tested at SDL.

Proprietary assembly techniques minimized assembly schedule to within 2 weeks.

Detailed tolerance analysis utilizing alignment compensators aided in the quick assembly process.

Active laboratory alignment was accomplished at SDL.
Active alignment steps:
- Telescope focus optimized for targets at infinity
- A black-body-illuminated-pinhole was aligned to the focus of an off-axis-parabolic mirror
- The telescope was placed in collimated space
- Focus compensators were adjusted for minimum pinhole images for both wide and narrow FOVs
Performance Testing of LWIR Telescope (First Generation Design)

- Laboratory results indicated insufficient photons were reaching the FPA
- Roof-top tests confirmed lab results
- Limited control of gain and integration time contributed to these results
- Measured SNR matched well to predicted SNR
- Results motivated a generation 2 design

Laboratory Extended Source Images

Wide FOV  Narrow FOV

Roof-Top Image
Modified Compact Dual-FOV LWIR Telescope (Generation 2)

- The low contrast test results motivated the design of a generation 2 compact dual-FOV LWIR telescope.
- The gen-2 design results in an SNR improvement factor of 3.8 and 2.2 over the gen-1 wide and narrow FOVs respectively.
- Gen-2 design adjustments included:
  - Broadening the spectral band
  - Changing the refractive elements to materials with higher transmission
  - Slight decrease in f-number
  - Requiring heaters (athermal range reduced due to the selection of different refractive materials)
- Gen-2 was not fabricated due to program redirection.
Compact Dual-FOV Concept for Small Satellites

The UAV compact dual-FOV telescope design concept may extend to Small-Sat applications requiring wide and narrow FOVs:

- The concept is well suited for Small-Sat applications due to their limited payload volumes
- May be applied to any spectral band of interest
- Will apply lessons learned from gen-1 and gen-2 experience

Simulation to the right shows how a space object may appear in a dual-FOV sensor with a field ratio of 6.

Simulation: Wide FOV (1 X)

Simulation: Narrow FOV (6 X)
Summary / Conclusions

- SDL successfully designed and fabricated a compact dual-FOV LWIR telescope for a small UAV application
  - Field ratio of 6 between the wide and narrow FOVs
  - Proprietary assembly/alignment techniques allowed fast fabrication
  - Low contrast test results motivated a generation 2 design with a predicted significant improvement in SNR and contrast

- This compact design approach may extend to Small-Sat applications with wide and narrow FOV mission objectives
  - Design concept may be applied to any spectral region of interest from the UV through the LWIR
  - Known design variations allow for flexibility in matching to a given application and/or set of mission requirements

- Well suited to Small-Sat applications because of its compact nature