Tunable, Narrowband Filter for LWIR Hyperspectral Imaging

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June 16, 1999

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Program Objectives

- Fabricate a prototype tunable filter based on liquid crystal-filled Fabry-Perot etalon (LCE).
- Enable voltage-controlled, tunable, narrow-band filtering at LWIR wavelengths
- Bandpass tunable at 60 Hz frame rates
- Enable rapid scene characterization for camouflaged target, or chemical identification
- Ability to build up Hyperspectral data cube with scanning software
Digital IR Microcam Camera Set-up

- Digital 8-12 micron IR Microcam Camera mated with a IR filter wheel holder.
- Using existing F1, 33°x25° field of view lens

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Hyperspectral Liquid Crystal Etalon

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Potential Applications: Camouflage Penetration
LWIR Comparison of Target & Background

ERIM data shows typical paint, tree canopy and camouflage spectra in the 8 to 12 \(\mu m\) range. We selected filters to capture data around the SCUD spectral feature. This was compared to data from pictures on either side of the feature.
LWIR Comparison of Camouflage Paints

FTIR spectrum of camouflage paints. Our measured data of several paint samples shows that the spectral features are actually much larger than those provided by ERIM.
Potential Applications: Standoff Plume Detection

Minimum detectable SF6 Concentration
(Against 300 K Earth background)

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Phase difference between two successive rays is the optical path plus the phase shift from two reflections

\[
T_x = \left[ 1 - \frac{A}{1 - R} \right]^2 \cdot \left[ 1 + \frac{4 \cdot R}{(1 - R)^2} \cdot \sin \left( \frac{2 \pi \cdot n(v) \cdot d \cdot \cos(\theta)}{\lambda_0} + \delta(\lambda) \right) \right]^3
\]

Where:
- \( A \) = mirror absorption
- \( R \) = mirror reflectivity
- \( n(v) \) = LC index of refraction, and is a function of applied voltage
- \( d \) = LC thickness
- \( \lambda_0 \) = free space wavelength of incident light
- \( \delta(\lambda) \) = phase shift on reflection
- \( \theta \) = incident angle of rays entering LC

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LCE Transmission Model

Three runs at $n(\nu) = 1.572, \text{ mid, and } 1.857$

Transmission tuning range: 8.7 to 10.55 $\mu$m

Bandpass: 0.1 $\mu$m FWHM

Free Spectral Range: 2.4$\mu$m
Changing Gap Changes Interference Order, Bandpass

5.75 um gap, 3rd order
0.22 um bandpass

11.25 um gap, 5th order
0.10 um bandpass

8.5 um gap, 4th order
0.13 um bandpass

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Reflection phase is critical to LCE gap size

<table>
<thead>
<tr>
<th>Wavelength (um)</th>
<th>Phase shift (deg)</th>
<th>Wavelength (um)</th>
<th>Phase shift (deg)</th>
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*Calculated from thin film model of dielectric mirror. Phase shift is a function of wavelength.*
Plot of effective index of refraction of the LC, as the applied voltage causes the molecules to tilt. Note that the effective index also depends on the angle in which the light ray traverses the crystal.
System Issues

Filter before the lens

Bandpass peak shifts radial across FPA

Shift in spectral pass of filter when located on object side of lens

% shift in bandpass (@ 10 um)

% of field from center of image plane

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System Issues

Filter after the lens

Bandpass widens depending on F#

Widening in filter bandpass due to F-cone
(calculated for 10 µm wavelength)

% spread in bandpass

0% 1% 2% 3% 4% 5%

1 1.5 2 2.5 3 3.5

F-number

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System Design: Relay Reduces Stray Light
LCE/camera System Model

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<td>Temperature of background</td>
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<td>Atmospheric ext. coeff.</td>
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</tbody>
</table>

Pfo Pfa = 0.001, Required TNR = 3.09
Pfo Pd = 0.999, Required SNR = 6.18
Min DEL Temp to detect @ 200 ft = 0.81 K
Maximum Detection Range = 537 ft
SNR at 0 ft Range = 8.57
SNR at 200 ft Range = 7.59

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Liquid Crystal Etalon

- Physical Diameter: 50.8 mm
- Clear Aperture: 45 mm
- Refractive Index: 1.57-1.86 μm
- Free Spectral Range: 2.4 μm
- Gap (LC thickness): 8.5 μm
- Tuning range: 8.7 to 10.7 μm
- Bandpass FWHM: 0.13 μm
- Resolution: 1.3%
- Finesse ≥ 20
- Mirror material: ZnSe
Task 2: IR Camera Trade-off

- Model calculates MRTD at 200 ft. based on LCE properties and camera f#, FOV, spectral band pass, etc.
- Must determine system limitations with best available cameras
- Cameras to be considered: QWIP, HgCdTe, Microbolometer, BST
Conclusions

- Rapidly tunable narrow band LWIR filter
- Convert LWIR camera to Hyperspectral imager
- Create Hyper-data cube with scanning software
- Applications include chemical and target identification
- Suitable for terrestrial and space born applications
- Prototypes available in 2000