Miniature Echelle Grating Spectrometer Cartridge

Current missile defense systems do not identify the content of an intercepted warhead payload. Spectral sensors could be used remotely to "type" the intercepted warhead based on detection of key signatures of warhead components. A platform for such a sensor is the last stage of the booster that releases the kill vehicle. To be compatible with this platform, a ten-fold reduction in size, weight, and power as compared to existing technology would be required. We have verified the optical feasibility of a sensor miniaturization concept, based on proven cross-dispersive spectrographic techniques used in larger systems. Figure 1 shows the context of a possible sensor concept relative to an interceptor.

Using an echelle grating spectrograph (EGS), which disperses light in two orthogonal directions to efficiently fill a 2-D focal plane, high spectral resolution is attained at the relatively high frame rates needed for short-lived events such as explosions. The dramatic reduction in size (Table 1) was due to the use of immersive gratings; a multipass architecture; folding the beam path; the physical combination of a grating and focusing element; and the availability of advanced diamond fly-cut ruling technology. Two records of invention were generated.

Table 1. Summary of improvements.

	EGS (existing)	MiniEGS (proposed)	Improvement factor
Optical path volume	6600 cm^2	100 cm^2	66x reduction
Cooler power	1000 W	200 W	5x reduction
Cool-down time	10 h	1 h	10x reduction
Optical transmission	Fiber fed	All-reflective optics	10x increase
Frame rate	10 Hz	100 Hz	10x increase
Dewar and cooler assembly weight	300 lb	20 lb	15x reduction
Total system weight	600 lb	60 lb	10x reduction

Project Goals

After performing initial scoping and exploration in FY2004 of a compact echelle spectrograph, we sought to demonstrate a configuration that has the high strategic potential of performing real-time, remote-target forensics on warheads as they are being destroyed. We focused on the mid-wave IR band with an approach that is extendable to other IR bands to collect potential nuclear warhead signatures of uranium, plutonium,

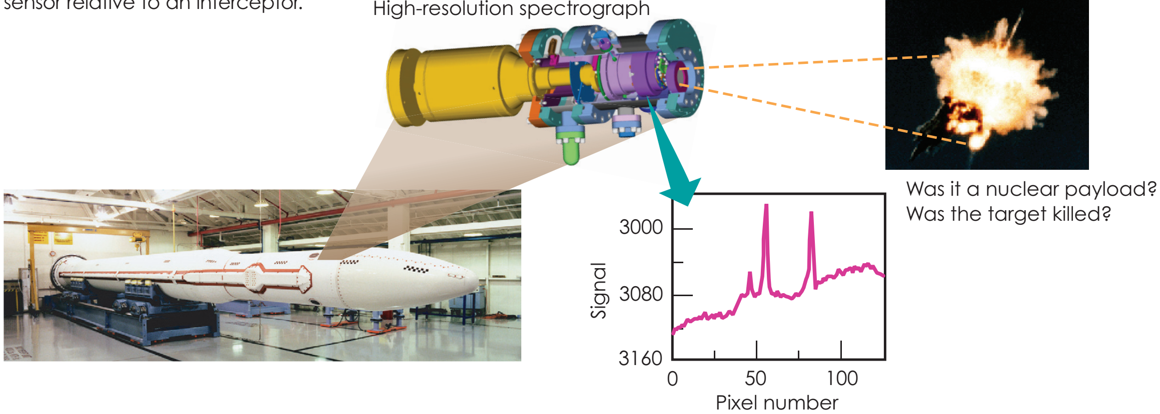

Figure 1. Notional context of sensor relative to an interceptor.

For more information contact
Joel Bowers
(925) 423-6877
bowers2@llnl.gov

tritium, their potential compounds, and high-explosives combustion by-products. This evidence would be critical to support decision processes that would likely follow an attack.

The down-selected optical systems were incorporated into precision mounts that maximized use of an existing cartridge-style mechanical infrastructure developed at LLNL for hyperspectral remote detection of WMD production signatures. This relatively modest investment of a new optical cartridge configuration created a completely new instrument concept (Table 2). The goal was to complete a feasible configuration for an echelle spectrograph optical cartridge, including optical prescriptions, performance predictions, an FPA technology assessment, and an optomechanical cartridge packaging concept.

Relevance to LLNL Mission

LLNL's national security mission requires special multidisciplinary capabilities that are also used to pursue programs in advanced defense technologies. The small form factor makes this sensor attractive for other applications requiring high spectral resolution and low volume, weight, and power.

FY2005 Accomplishments and Results

The optical configuration was refined and characterized with regard to diffraction efficiency, ghosting, and stray light analyses. The very high spectral resolution of one-quarter of a wavenumber over the mid-wave IR spectrum was verified. Out of necessity for optical formatting, we invented a microperiscopic beam-slicer (Fig. 2) that will rearrange an incoming 3-x-3 pixel array into a 9-x-1 array at the sensor entrance slit.

Commercial off-the-shelf focal plane array technologies were investigated and verified for feasibility at this form factor. The mechanical study was completed after modeling the cross-dispersive configuration and identifying components of the existing hyperspectral optical cartridge that could be used without modification in the new system. Estimates were generated based on this gap analysis to determine the complete scope of the effort needed for a prototype system.

Related References

1. Kuzmenko, P. J., D. R. Ciarlo, and C. G. Stevens, "Fabrication and Testing of a Silicon Immersion Grating for Infrared Spectroscopy," *Optics, Imaging, and Instrumentation*, *SPIE*, **2266**, pp. 566-577, 1994.
2. Stevens, C. G., P. Kuzmenko, T. W. Alger, and N. L. Thomas, "An Echelle Grating Spectrometer (EGS) for Mid-IR Remote Chemical Detection," *Optics, Imaging, and Instrumentation*, *SPIE*, **2266**, pp. 2-12, 1994.
3. Thomas, N. L., S. A. Johnson, and C. G. Stevens, "Design of an Immersion Echelle Grating Mid-IR Spectrograph for Chemical Remote Sensing," *Optics, Imaging and Instrumentation*, *SPIE*, **2266**, pp. 13-24, 1994.
4. Hulthen, E., and H. Neuhaus, "Diffraction Gratings in Immersion," *Arkivfur Fysik*, **8**, pp. 343-353, 1954.
5. Hinkle, K. H., S. T. Ridgway, and F. E. Stuart, "Optical Design for a High Resolution, 2-5 Micron Infrared Cryogenic Echelle Spectrometer," *Instrumentation in Astronomy*, *SPIE*, **1232**, 1990.

FY2006 Proposed Work

A key technology that was invented in this project is the microperiscopic image slicer, consisting of an internally reflecting mirror system that is a fraction of a millimeter in size. This enabling technology will require a mesoscale manufacturing demonstration to determine credibility of the concept.

Table 2. Optical parameters.

Spatial image format	3 x 3
Reformat to spatial slit	9 pixels
Spectrometer f-number	4
Detector array	256 x 256 with 30-µm pixels
Wavelength range	3.1 to 4.8 µm
Wavelength resolution	0.25 wavenumber/ pixel equivalent to 0.4 nm at 4 µm)
Number of pixels along spectrum	4250
Orders to cover spectrum	~17 orders
Number spatial pixels assigned to each row	13 pixels

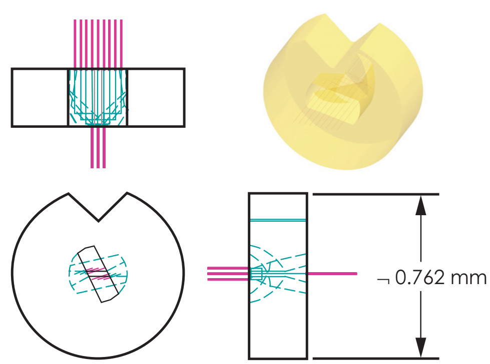

Figure 2. Microperiscopic image slicer.