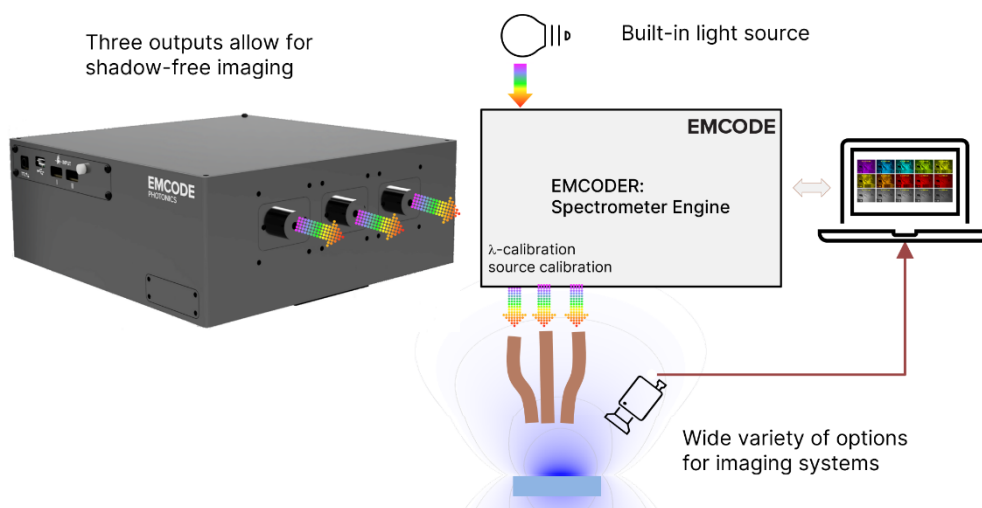


SWIR hyperspectral system



Emcode's SWIR hyperspectral system, operating from 900 nm to 1700 nm, includes everything needed to obtain precise hyperspectral data. The standard system features Emcode's proprietary coded light source, a SWIR camera (with several camera options available), a complete set of APIs, and fully functional stand-alone software, allowing you to begin capturing data immediately out of the box. The hyperspectral cube is constructed at the camera's resolution without requiring any scanning or interpolation algorithms.

The Emcode light source provides three coded light outputs to illuminate the device from different angles, ensuring uniform illumination and shadow-free imaging. Internally, the Emcode system tracks the coded output spectra and continuously performs wavelength calibration using a known atomic absorption colored glass standard. The coding gain and ability to use high-NA optics allows less than 3 mW of coded light to reach excellent SNR (see Considerations in selecting SWIR camera).

The SWIR camera is synchronized with the emcoder's light source, and the data is decoded by the PC to generate the hyperspectral cubes. There is no need for dark or fixed pattern measurements or concern about source drifts, as these are continuously monitored and corrected.

The data is saved in an industry-standard format for seamless analysis.

1. Specifications

Parameter	Value	Comments
Wavelength range	900 nm - 1700 nm	Customize for water with 1200 nm to 1600 nm with faster hypercube rate
Number of spectral bands	32 or 64	Evenly spaced.
Spectral resolution	25 nm for 32 spectral bands 12.5 nm for 64 spectral bands	
Camera resolution (Some select choices)	320 X 256 - 15 μm pixel, $\sim 50 e^-$ noise 640 x 512 - 15 μm pixel, $\sim 50 e^-$ noise 1296 x 1032 - 5 μm pixel, $\sim 200 e^-$	Pixel binning will increase SNR. Light collection depends on the area of the pixel.
Wavelength calibration and source spectra	Built-in and available continuously	Continuously calibrated against an atomic glass filter
Software	Analyze, examine, and save spectral cubes via UI or Python APIs.	See section 4: Brief description of the software
Pixel-level SNR per hypercube	Close to camera's intrinsic SNR	Coding removes systematic noise and drifts.
Emcoder size	6.5" X 6.5" X 2.5"	Mounting holes for optical breadboard
PC requirements	Needs USB 2.0 for the Emcoder and USB 3.0 for the camera	Windows 10 or higher. 32 GB RAM Modern CPU recommended Python 3.12.

2. Budgetary Quote

\$12,500 for Emcoded light source with software. Add camera and lens system.

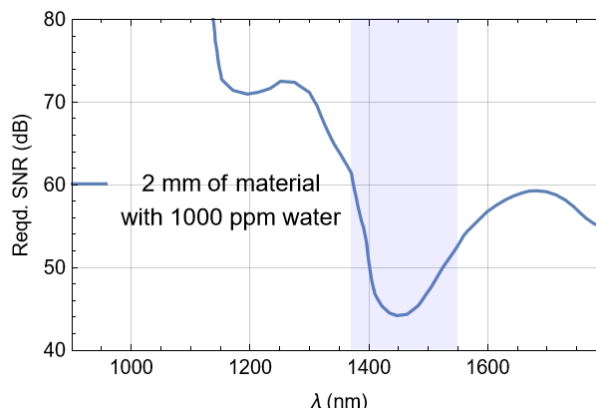
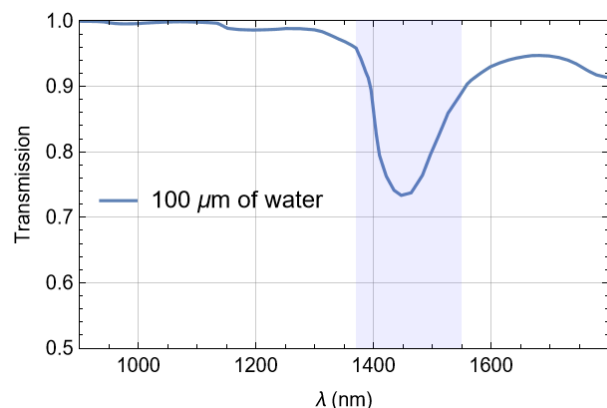
320 X 256 - 15 μm pixel, $\sim 50 e^-$ noise; USB 3	$\sim \$ 7,000 + \text{lens}$
640 x 512 - 15 μm pixel, , $\sim 50 e^-$ noise; USB 3	$\sim \$12,500 + \text{lens}$
Sony IMX990: 1296 x 1032 - 5 μm pixel, $\sim 200 e^-$ noise; USB 3	$\sim \$15,000 + \text{lens}$

SWIR lenses range from \$600 to \$2500.

3. Considerations in selecting SWIR camera

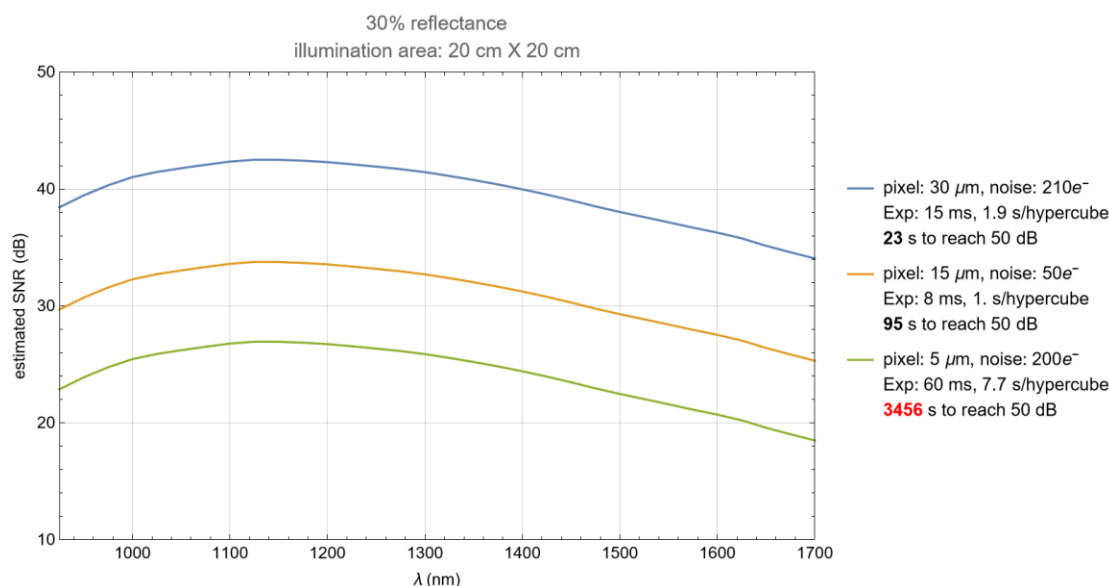
1. Larger pixels collect more light (proportional to the area of the pixel). This enables imaging larger area and reach same SNR for a fixed amount of illumination. The choices here are Sony's smaller pixels with wide wavelength coverage vs traditional InGaAs photodiode array-based images with pixel size ranging from 15 μm to 30 μm . The cost of the camera scales with the area of the focal plane array.
2. Hypercube rate is equal to the frame rate of the camera divided by four times the number channels. Frame rate is either limited by maximum frame rate of the camera or the exposure time necessary to get sufficient signal on the pixel.
3. The SNR of each frame depends on the combination of read-out noise and shot noise.
4. One needs to understand the spectral SNR requirements for the required measurement.

As an example, consider measuring moisture or detecting the presence of water in a material by analyzing water's absorption at 1460 nm. The figure below illustrates water's absorption spectrum from 900 nm to 1700 nm for a 100 μm -thick water column. It also shows the signal-to-noise ratio (SNR) required to detect water at a concentration of 1000 ppm in a 2 mm-thick material, equivalent to a water thickness of 2 μm .



The following plot estimates the SNR for a 32-spectral-channel Emcode light source used with three different camera options, each featuring distinct pixel sizes and noise characteristics. In each case, we are assuming that the output of the Emcode is arranged to illuminate a 20 cm X 20 cm area. The three outputs from the Emcode on a 0.22 NA fiber allows for efficient and shadow-free illumination.

In the plot below, the exposure time has been adjusted for each sensor to achieve approximately 70% of its well capacity.



The above plot points to using a traditional InGaAs sensor with bigger pixels and smaller noise floor since these sensors significantly outperform the relatively new Sony sensor with 5 μm pixels. This can be seen by comparing the total time required to reach 50 dB SNR as noted in the legend for each of the sensors.

EMCODE

PHOTONICS

Data from many pixels as well as many spectral bands can be combined for analysis. Whether combining spectral bands or pixels, one gains SNR by \sqrt{N} . Thus, combining a 10X10 pixel region will provide 10X or 20 dB boost in SNR and combining 4 spectral bands will provide 2X or 6 dB boost.

4. Brief description of the software

The Python-based user interface (UI) is built using Emcode's C++ APIs, serving as an example of how applications can be rapidly developed on top of robust APIs.

The UI offers powerful visualization and data analysis capabilities, including:

- Examining slices of the hypercube.
- Generating virtual RGB images by combining spectral information.
- Saving hypercube data with the option for saving a series of time-lapse cubes.
- Extracting spectra from regions of interest.
- Saving time-series of spectra from specific regions of interest.

The APIs enable a wide range of functionalities, including:

- Initializing the Emcode system.
- Configuring camera settings such as frame rate, gain, exposure time, and region of interest (ROI).
- Providing hypercube data sets complete with source spectra and wavelength maps.
- Averaging hypercubes to optimize signal-to-noise ratio (SNR).
- Saving data cubes for further analysis.

Users have the flexibility to develop their own Python applications or operate the Emcode system through scripting tools like Jupyter Notebook for streamlined data acquisition and analysis.

Contact: info@emcodephotonics.com for further information and to discuss your application.