Release

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IMAGEVAL CONSULTING

ISET

Image Systems Evaluation Tool

Manual

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Introduction

***ISET** is designed to help clients evaluate how imaging system components and algorithms influence image quality.*

ISET is a software package developed by **Imageval Consulting.** Using ***ISET*** the user can measure and visualize how changes in image systems hardware and algorithms influence the quality of the image. The software allows the user to specify and explore the influence on image quality of physical properties of visual scenes, imaging optics, sensor electronics, and displays. ***ISET*** is a unique tool that lets the user trace the effects of individual components through the entire imaging system pipeline.

The software package uses a Graphical User Interface (GUI) to enable the user to intuitively and efficiently manipulate the various components within the image systems pipeline. Through this simple-to-use interface, the user can specify the physical characteristics of a scene including the viewing conditions (e.g. radiance, viewing distance, field-of-view, etc), and define many parameters of the optics, photodetector, sensor electronics and image processing-pipeline.

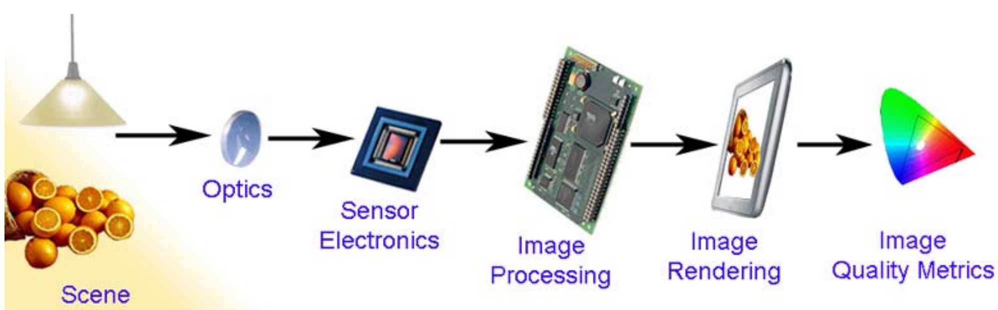
ISET also allows the user to quantify the characteristics of the individual components within the image systems pipeline. The package includes methods of calculating optical modulation transfer functions (MTFs), pixel and sensor signal-to-noise ratio (SNR), and color tools based on international standards (CIE chromaticity coordinates, color matching functions, CIELAB metrics and others) to evaluate the image quality of the processed image.

Based on the **Matlab** (trademark) development platform and an open-software architecture, ***ISET*** is extensible and its data are accessible to users who wish to add proprietary computations or who simply wish to experiment.

Systems Approach

People judge an imaging system based on the final output rendered on a display or a printer. But the quality of the rendered output is determined by the sequence of image transformations that occur before and during image rendering. To identify the source of a visible distortion, we need to simulate and evaluate the entire imaging system, from image capture to image processing, transmission, and rendering.

ISET simulates a complete imaging system beginning with a radiometric description of the original scene, optical transformations, sensor capture, and digital image processing for display. The user explores the image system properties using a suite of integrated windows that allow the user to view and alter the key physical objects in the image systems pipeline. The key elements are referred to as the **Scene**, **Optics, Sensor**, and **Processor**.



Graphical User Interface

ISET consists of a suite of integrated windows that allow the user to view and alter the key physical objects in the image systems pipeline. The principal windows are referred to as the Scene, Optics, Sensor, and Processor.

ISET is launched from a Matlab command window by typing `ISET.` This begins a **Session**, which is an integrated record of all of the **Scene**, **Optics**, **Sensor** and **Processor** objects and their properties. The program opens a small window that allows the user thorough control of the main steps in the imaging pipeline. The program also creates a **Session** variable that is used to store the data created and analyzed during program execution.

Each **Session** can store multiple objects making it easy for the user to switch back and forth between parameter settings and compare results as parameters and processing change. To create or edit different objects, the user opens a window designed to interact with that type of object.

The windows controlling each of the objects are organized by a set of **pull-down menus** and **editable boxes**. The **Pull-Down Menus** in all of the object windows are organized in a similar, familiar way.

- **File:** This menu allows users to load and save the information defined in each window.

- **Edit:** This menu allows users to delete, rename or edit properties of the objects associated with that window.

- **Plot:** This menu enables the user to plot data associated with the current object. For example, the user can select and plot the radiance in any area in the **Scene** window. The user can plot the modulation transfer function, pointspread and linespread functions in the **Optics** window. The user can plot the spectral data for filters and sensors used in the current **Sensor** window and the data characterizing the display properties associated with the current **Processor** window.

- **Scene, Optics, Sensor, Processor:** Each window has a pull-down menu for importing data sets and adjusting the parameters of the object specific to that window. The **Scene** window has a pull-down menu labeled "Scene" to select the scene or targets. The **Optics** window has a pull-down menu labeled "Optics" to load optical parameters for standard optical formats. The **Sensor** window displays a pull-down menu labeled "Sensor" to load sensor parameters of CIF, VGA or customized sensors that are stored in a file. And, finally, the Processor window has a pull-down menu for loading display parameters such as the spectral power distribution of color channels, the spatial layout of pixels, the display gamma, etc.

- **Analyze:** Each window has a menu that lets users calculate various metrics and measurements. For example, the user can select and plot the CIE chromaticity coordinates for areas in the Scene and Optics images. The user can create 3D pseudo-color coded images that represent the luminance and illuminance in the **Sensor** and **Optics** images. The user can calculate and plot Line, Region of Interest and SNR statistics for the **Sensor** image. And the user can calculate color image quality metrics (such as CIE ΔE) and spatial image quality metrics (such as DCTune and PSNR) for the Processor image.

- **Help:** The help menu directs the user to an online manual page that describes the functionality of that window.

Each window has an editable box for specifying the **display gamma** for the monitor that the window is displayed on. This has the effect of changing the appearance of the image displayed in the window, but it does not influence the underlying data.

Each window has buttons and editable boxes for specifying properties associated with the current object. For example, the user can specify the physical dimensions of the scene, F-number and focal length of the optical lens, sensor noise properties, color filter array, color image processing algorithms, etc. The properties that users can specify and measure are listed for each window in the separate sections below for **Scene**, **Optics**, **Sensor** and **Processor**.

Installation

CD Installation

To install the ISET software, perform the following three steps.

1. Copy the contents of the ISET directory from the ISET-CD into a suitable location on your computer. We suggest placing the distribution inside of the user's Matlab working directory, say

   C:\myhome\Matlab\ISET.

2. Copy the file 'isetPath.m' to a location that is always on your path when Matlab starts up. For example, place 'isetPath.m' in

   C:\myhome\Matlab

Before running ISET, you must add the program and its sub-directories onto your path. To do this, you can simply type

isetPath('C:\myhome\Matlab\ISET');

If you wish to run ISET routinely, you can put the isetPath() command in your startup file.

Users Manual and Online Help

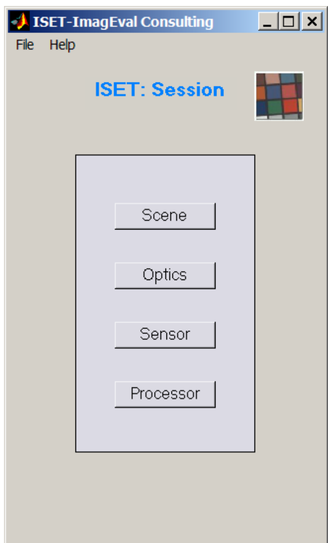
This user manual and related help files are maintained and updated online. By pressing the Help button on any of the ISET windows, a browser will open to the relevant section of the manual.

A version of this manual in PDF-format is also on the distribution CD in the Documents sub-directory.

QuickStart

If you like to explore software just by running it and exploring, we suggest you get started by following these instructions. If you would rather read more about the software, please continue to the next section.

Install the ISET tools on your Matlab path (see Installation). Enter ISET at the Matlab prompt.



The Session window will appear. Press the **Scene** button. This will bring up a window in which you can create and explore various types of scenes. To get started quickly, under the Scene pull-down menu, select Macbeth D65. This will produce an image of a standard color test chart in the **Scene** window. Other test targets can be selected from the Scene pull-down menu, as well.

Under the Plot pull-down menu, select Radiance. You will be asked to choose a region of the image using the mouse. Once you have done so, a graph window will appear showing the underlying spectral radiometric image data: The radiance of the scene at that location within the image.

Return to the **Session** window and click on the **Optics** button. A new window will appear with a default set of assumptions about the optics. Click on the large 'Compute Optical Image' button towards the bottom of the window; ISET will compute an image of the irradiance at the sensor and show an estimate of the image. You can plot the irradiance at the sensor, alter the parameters of the optics, and measure other features of the optical image, from this window.

Next, return to the **Session** window and click the **Sensor** button. This will bring up a window with a default sensor. Clicking on the Compute Sensor Image button, will produce an image of the voltage responses across the surface of the default sensor. Using the Plot menu you can explore the current sensor parameters.

Finally, returning to the **Session** window, click on the **Processor** button. This will bring up a new window. By pressing on the 'Compute' button, you will render an image that illustrates how the demosaic'd and processed data will appear on a model display.

More details about each of these windows and their functionality are described in the section titled "Using ISET 1.0."

You can close any of these windows at any time, without losing the underlying data. Pressing on the **Session** button for that window will bring the window back up with all of the stored data.

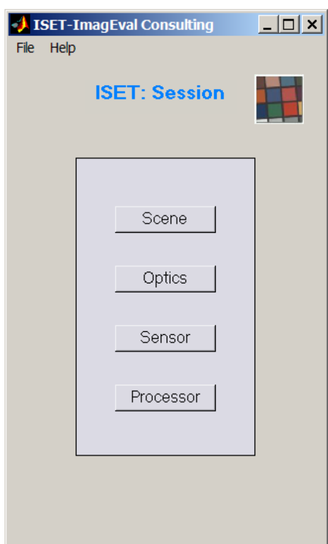
At any time, you can save the **Session** data from the File menu in the **Session** window. There, you can also save the data and close all of the ISET windows.

For programming: The data from the ISET session are stored in a large structured variable called vcSESSION. At present, the data can be extracted from this variable directly from the Matlab workspace. In the future, data will be extracted from this variable using object based routines including of the form, get(scene, 'parameter'). Currently, the files sceneGet, opticsGet, sensorGet, and vcimageGet are used to retrieve Session data as well as compute various important variables from the vcSESSION structure.

Using ISET 1.0

*The **ISET** software is organized into four main parts corresponding to four stages in the imaging pipeline. These are the Scene, Optics, Sensor, and Processor. The user creates and manipulates the objects and algorithms that transform the scene into an optical image at the sensor, the optical image into a sensor image, and the sensor image into a set of digital values for display.*

Session Window



After installing the software, type ISET into the Matlab prompt. A small **Session** window will appear. This window allows the user to access each of the principal object windows used to create and manipulate data. The four buttons in the window are ordered to follow the imaging pipeline: Data begin in the Scene, pass through the Optics, are captured by the Sensor and transformed by the Processor to yield a final display image.

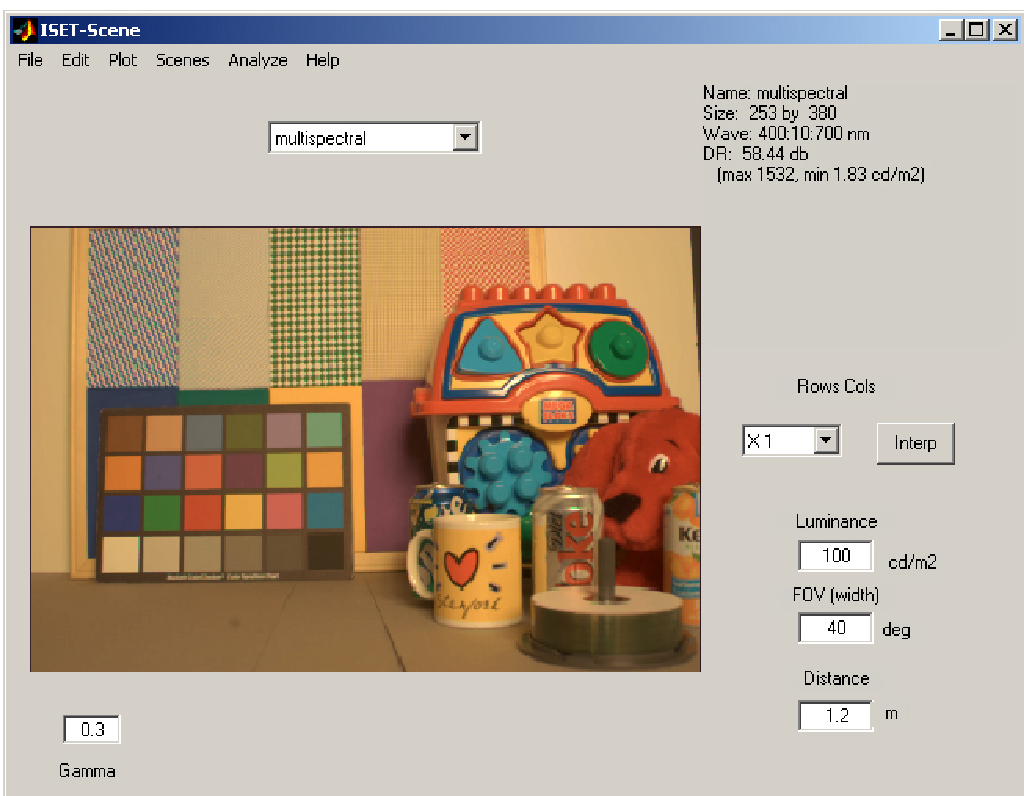
In this introduction we explain the main functions of each of these windows, in turn, and provide some examples of how the software can be applied to analyze the imaging pipeline.

Scene

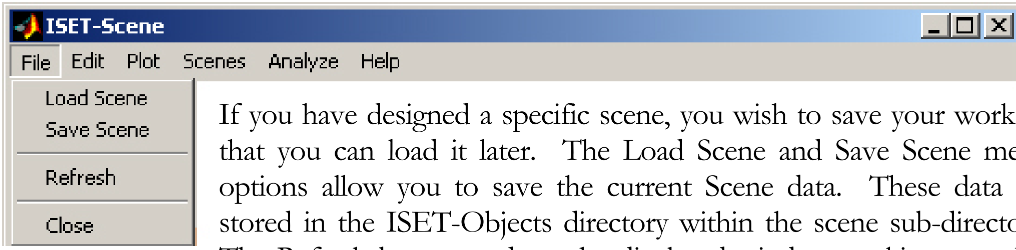
From the Scene window the user creates a variety of scenes. The data representing a scene are in radiometric format. The software assumes that the scene is restricted to a single image plane at a distance indicated by an editable box in the Scene window. The scene radiance data are encoded in multi-dimensional matrices containing spatial samples of the spectral data (photons/sec/nm/m^2). In addition, the data can be accessed in terms of energy, or the data can be converted into a luminance format (candelas per meter squared).

Scenes can be obtained from various sources. Several synthetic scenes that are useful for system evaluation can be generated from the Scene pull-down menu. Further, scenes can be generated from standard format image data. Finally, ImagEval provides a set of calibrated high-dynamic range scenes that can be read using the ***ISET*** software. (Appendix A describes how we measure and estimate the spectral radiance of natural scenes.)

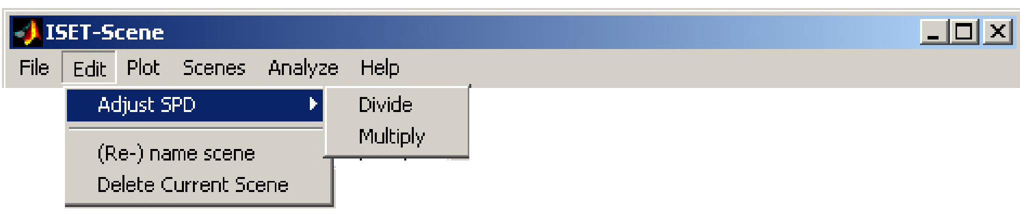
The figure below shows the Scene window and an image of a standard color target, acquired under tungsten lighting.



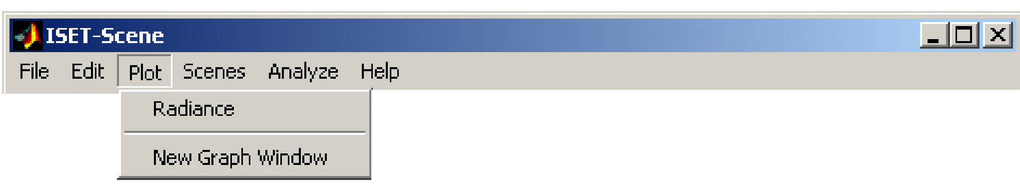
Scene: Pull-down menus



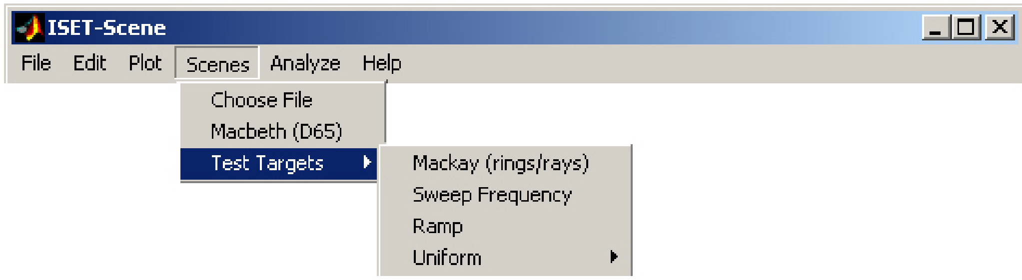
If you have designed a specific scene, you wish to save your work so that you can load it later. The Load Scene and Save Scene menu options allow you to save the current Scene data. These data are stored in the ISET-Objects directory within the scene sub-directory. The Refresh button updates the displayed window, making sure that the window display is consistent with the underlying data. This button is used in the case that you decide to run an independent program on the current scene data. If your program alters the Scene parameters, the Refresh button will update the display. The Close selection closes the Scene window. The data, however, remain in memory. Pressing on the Scene button in the Session window will open the window in the same state as when you close it.



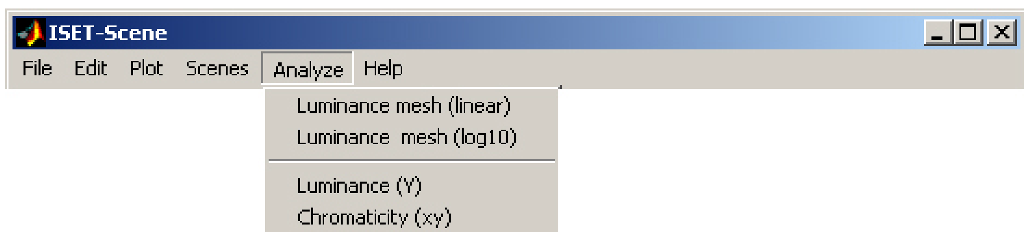
The Edit pull-down is used to modify various properties of the current scene. Adjust SPD permits you to divide or multiply the spectral photon distribution of the current scene by a function of wavelength. You can also Rename the current scene or Delete it.



The scene data are shown as a rough color approximation of the true data in the Scene window. To see the true spectral photon distribution of the data, you can use the Plot menu to show the Radiance. If you wish to compare the radiometric distribution at two locations, you may open a New Graph Window and plot the spectral photon distribution at another location from the window.



There are a variety of ways to create scenes. The simplest way to make a target comprising a set of uniform color patches is to press the Macbeth (D65) button. This will produce a radiometric image of color patches. Various simple test targets can be created to explore the spatial structure of the imaging pipeline. Or, if you wish to choose a jpeg, tiff or other file and use the data therein to make an estimated spectral photon distribution, you can select the Choose File option.



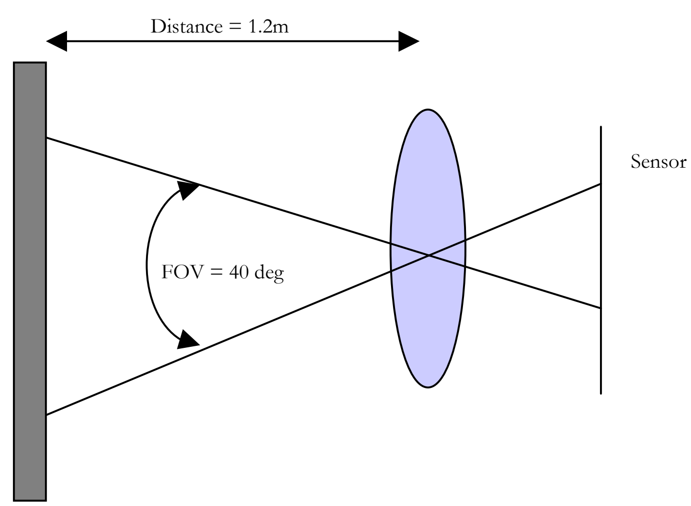
To analyze various properties of the scene, including its luminance distribution or the chromaticity coordinates of different locations, you can use the various options in the Analyze menu. The first two options produce three dimensional mesh plots of the luminance distribution. The second two options allow the user to select regions of interest (ROIs) within the image and analyze the luminance and chromaticity coordinates within those regions.

Scene: Editable boxes

Scenes have only a few simple characteristics. They are spatially sampled at some number of rows and columns. The current spatial sampling is shown at the upper right of the window. If you wish to change the spatial and row samples, you can scale the row and column samples with the pull down under Rows, Cols; or you can enter new values by pressing on the Interp button. In that latter case, a window appears that lets you set the row and column dimensions arbitrarily.

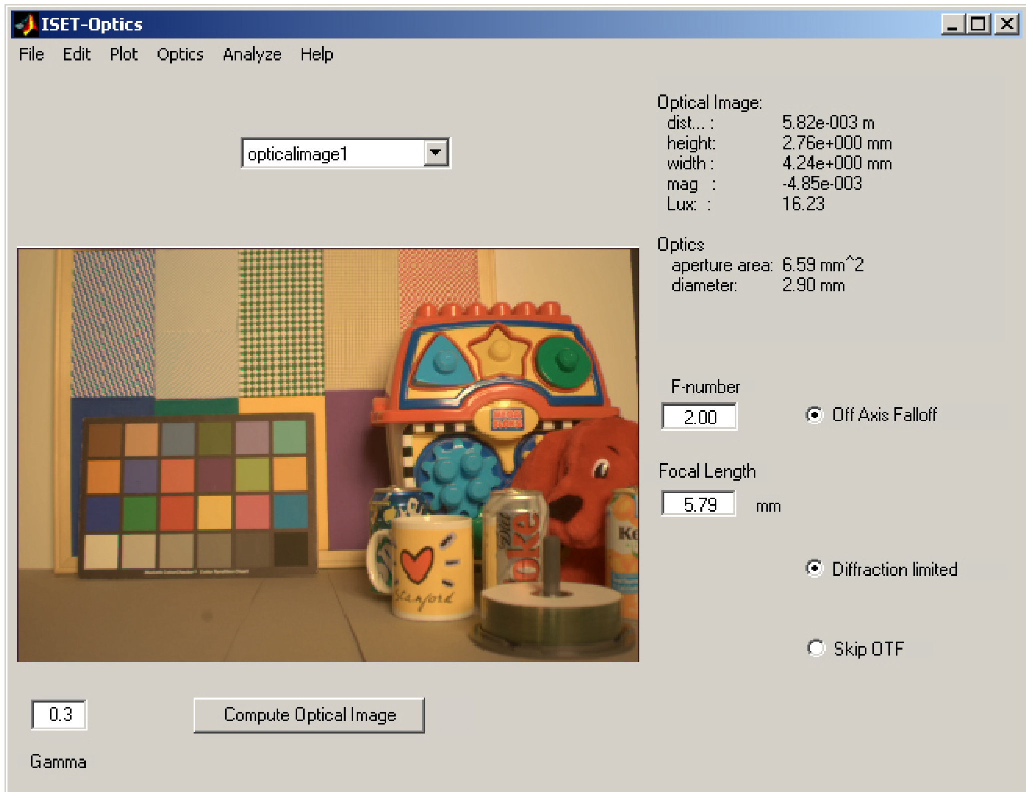
The mean luminance of new scenes is assumed to be 100 candelas per meter squared. If you wish to explore the effect of reduced, or increased, mean luminance you can change the value by adjusting the value in this box.

Finally, the field of view (FOV) of the scene is usually assumed to be 40 deg, which corresponds to the typical value for a digital camera. The FOV can be adjusted by entering a new value into this box. The scene is assumed to be a plane at some distance (meters) from the optics. This value can be changed as well.

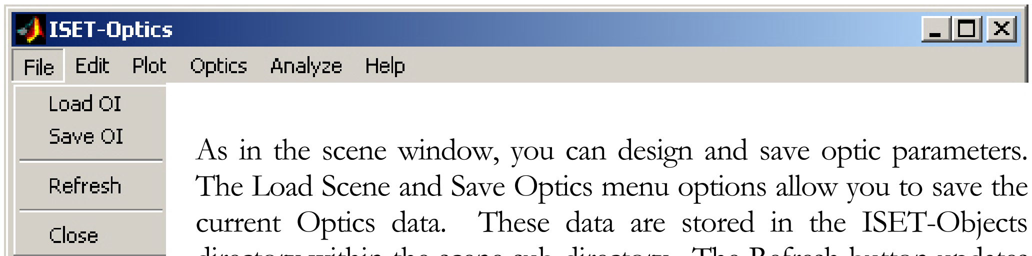


Optics

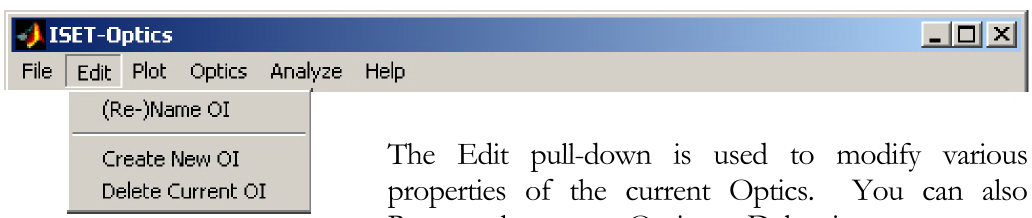
The image displayed in the Optics window represents …



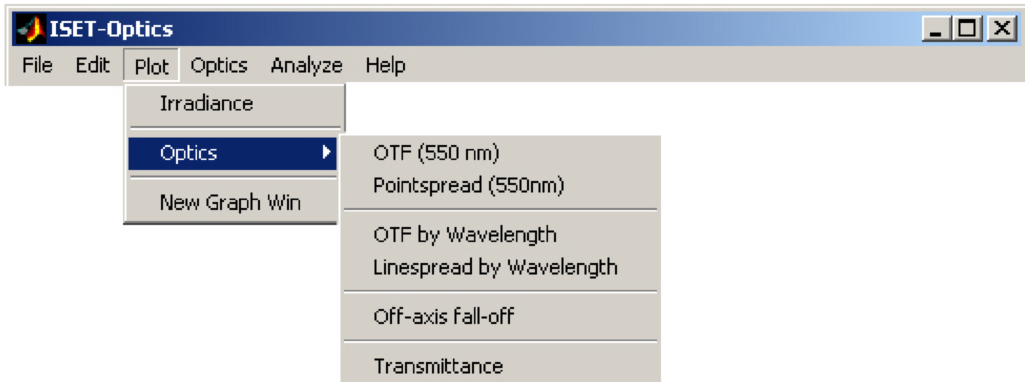
Optics: Pull-down menus



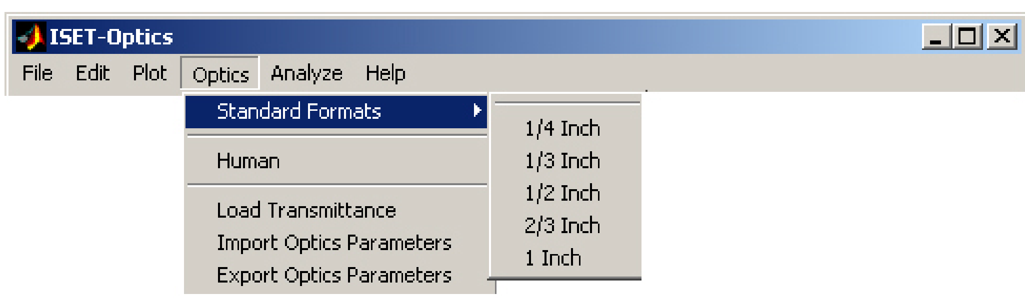
As in the scene window, you can design and save optic parameters. The Load Scene and Save Optics menu options allow you to save the current Optics data. These data are stored in the ISET-Objects directory within the scene sub-directory. The Refresh button updates the displayed window, making sure that the window display is consistent with the underlying data. If your program alters the parameters of the Optics, the Refresh button will update the display. The Close selection closes the Optics window. The data, however, remain in memory. Pressing on the Optics button in the Session window will open the window in the same state as when you close it.



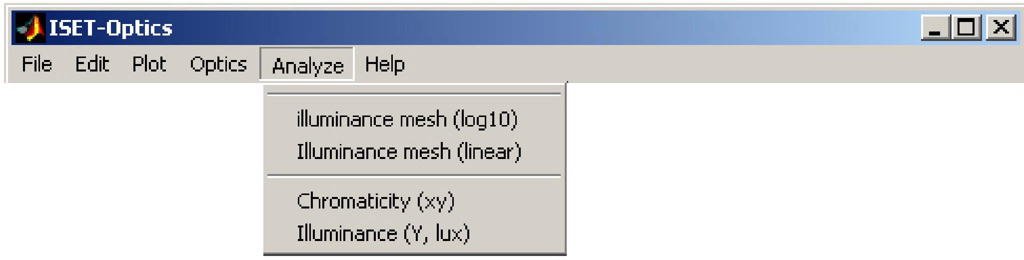
The Edit pull-down is used to modify various properties of the current Optics. You can also Rename the current Optics or Delete it.



The optical image is the photons incident on the sensor. It is possible to plot the irradiance data for any region in the optical image by selecting the "Irradiance" option in the Plot menu. You will be instructed to select a rectangular region of the image and the current graph window will show the spectral irradiance for that selected region. If you wish to compare the radiometric distribution at two locations, you may open a New Graph Window and plot the spectral irradiance at another location in the optical image. It is also possible to plot properties of the current optics, such as the optical transfer function (OTF) and the spatial pointspread function at a particular wavelength (550 nm.). By selecting "Off-axis fall-off" you can graph the intensity fall-off as a function of distance from the center of the lens. (This is often referred to as cosine fall-off.) Finally, it is possible to plot the spectral transmittance of the current optics.

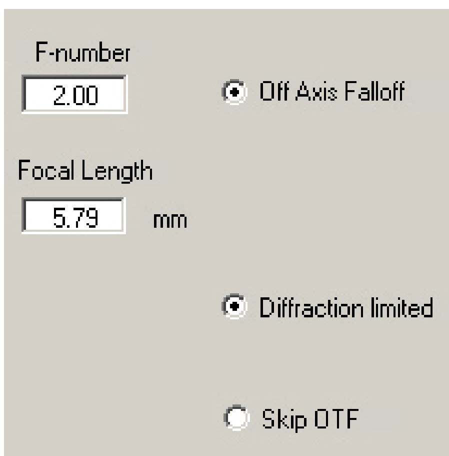


The Optics menu enables you to select stored properties of standard optical formats, such as ¼ inch, etc. Or you can select the properties of the human eye. This menu also enables you to change the spectral transmittance of the optics by selecting stored functions. Finally, one can export the current parameters (Export) and load them later (Import).



The Analyze menu allows you to view three-dimensional mesh plots of the illuminance distribution in the optical image. The second two options in the Analyze menu enable you to select regions of interest (ROIs) within the image and analyze the luminance and chromaticity coordinates within those regions.

Optics: Editable boxes



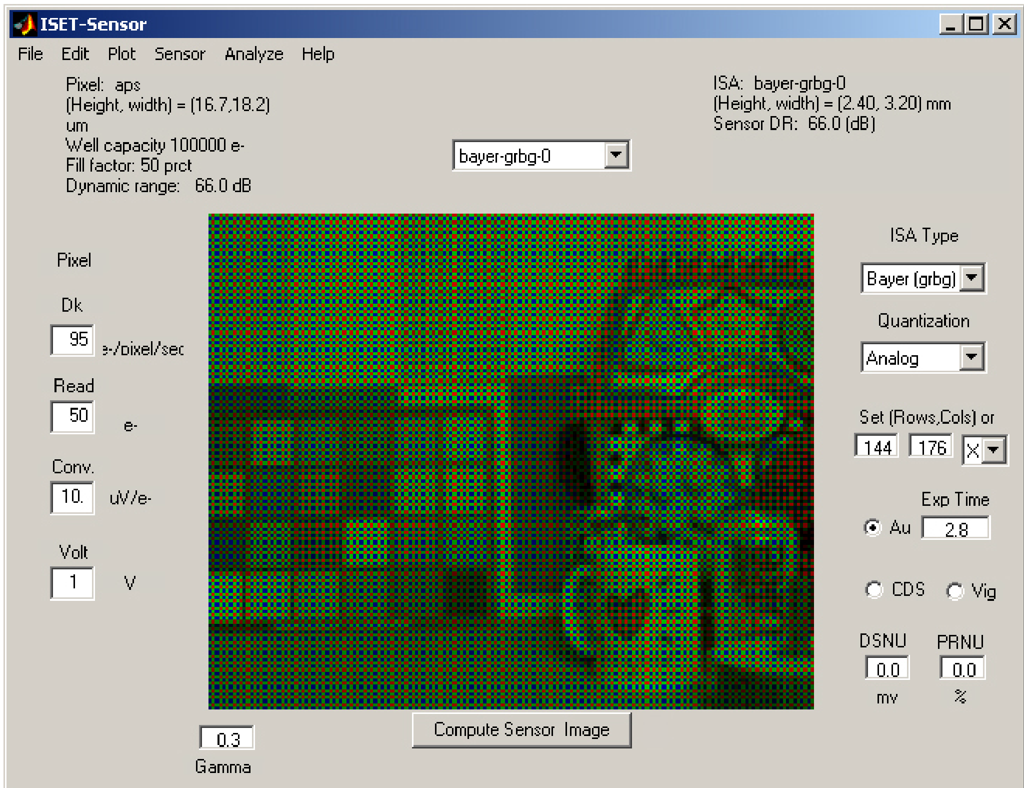
For a thin lens, which comprises the models to this point in ISET, the focal length describes the distance from the center of the lens to the image plane when the image is at infinity (incident rays are collimated). The f-number is the focal length divided by the aperture. A lens with a very large f-number typically has a small aperture. This reduces the amount of light falling on the sensor, increases the blur due to diffraction, but increases the depth-of-field.

Imaging optics concentrate more light towards the center of the image than the edges. This off-axis falloff is sometimes called vignetting. ***ISET*** includes this vignetting in the calculation by default. Finally, the optical blur introduced by a lens depends on many of the lens properties. For a perfect lens, however, the quality of the image is limited only by a fundamental physical limit imposed by the aperture size. By default, ***ISET*** includes diffraction-limited optics; the optical deformation can be eliminated entirely from the computational path.

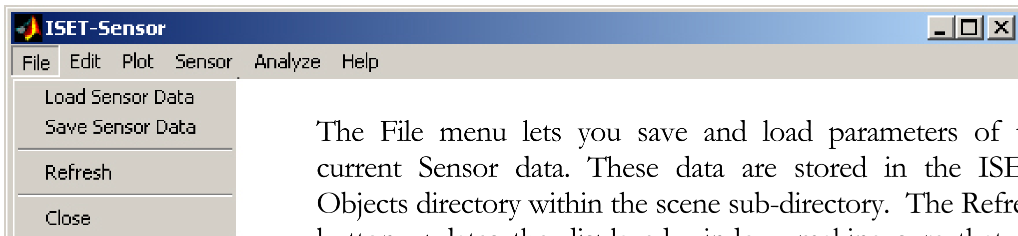
Additional optical models are expected in future versions.

Sensor

General remarks

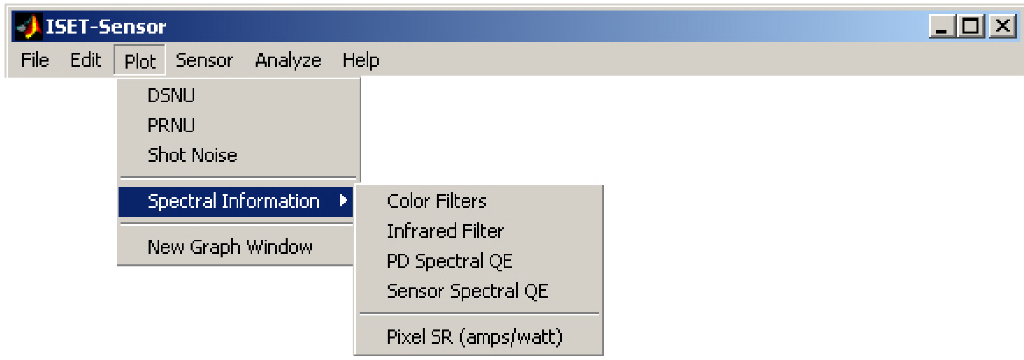


Sensor: Pull-down menus

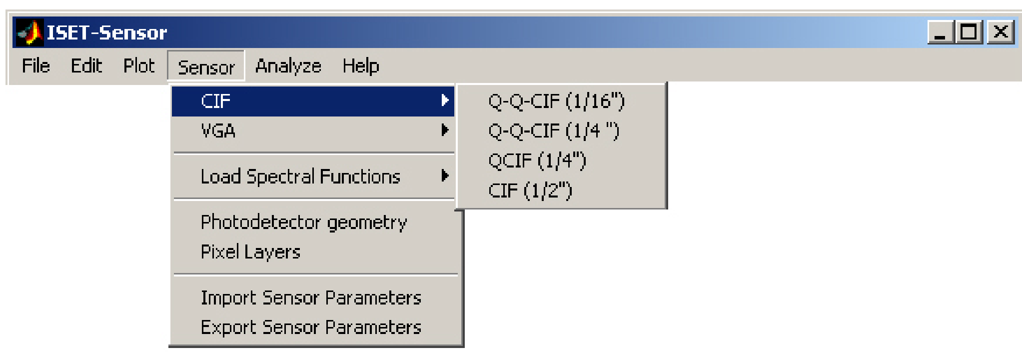


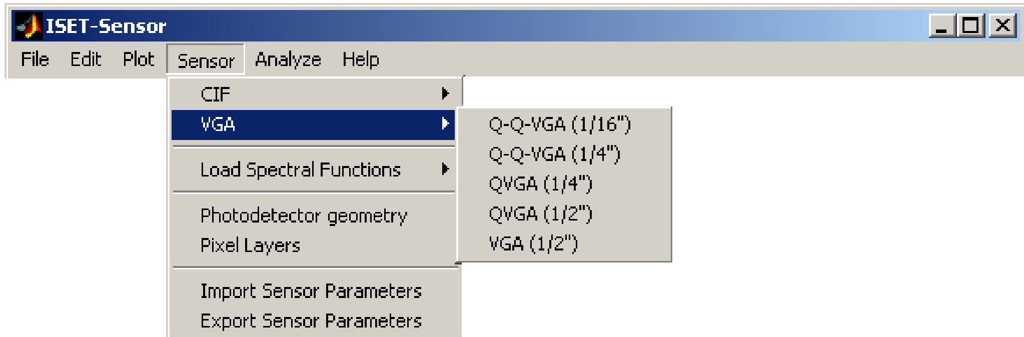
The File menu lets you save and load parameters of the current Sensor data. These data are stored in the ISET-Objects directory within the scene sub-directory. The Refresh button updates the displayed window, making sure that the window display is consistent with the underlying data. If your program alters the parameters of the Sensor, a red button will appear and you can use the Refresh to update the display. The Close selection closes the Sensor window. The data, however, remain in memory. Pressing on the Sensor button in the Session window will open the window in the same state as when you close it.

The Edit pull-down is used to modify various properties of the current Sensor. You can also Rename the current Sensor or Delete it.

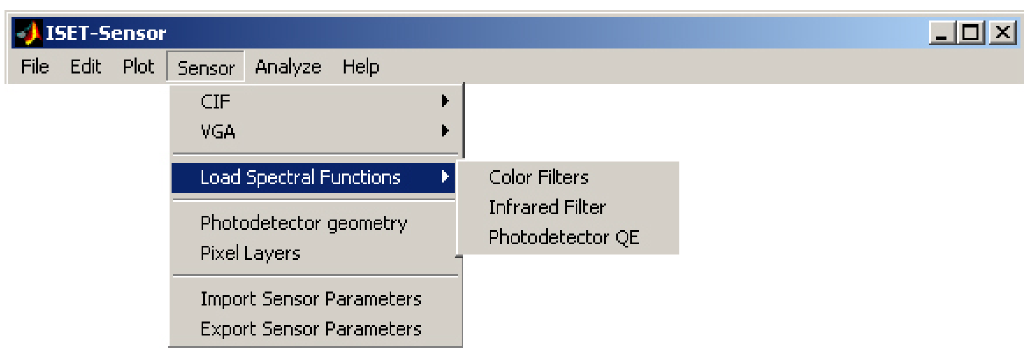


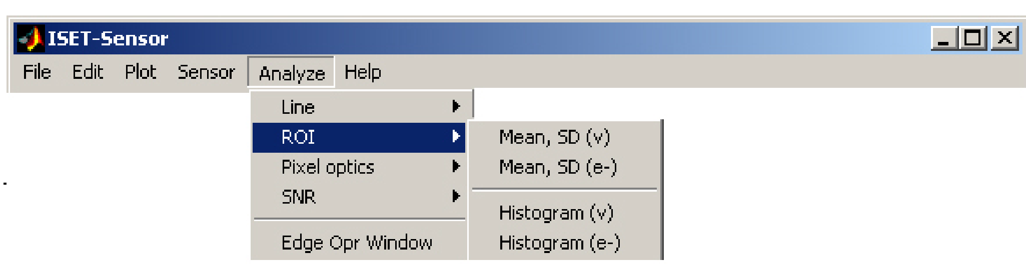
To see a graphical description of various spectral properties of the sensor, you can use the Plot pull-down and the Spectral Information component of the menu. Different components of the pathway, including Color Filters, Infrared Filter, the Photodetector Spectral Quantum Efficiency, and the overall Sensor Spectral Quantum efficiency that includes all of these terms, can be selected and plotted. Each of these curves can be changed by reading in new data from the Sensor pull-down menu, in the Load Spectral Functions component.

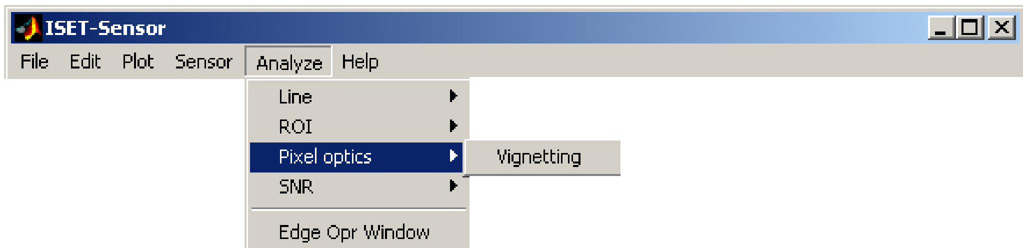




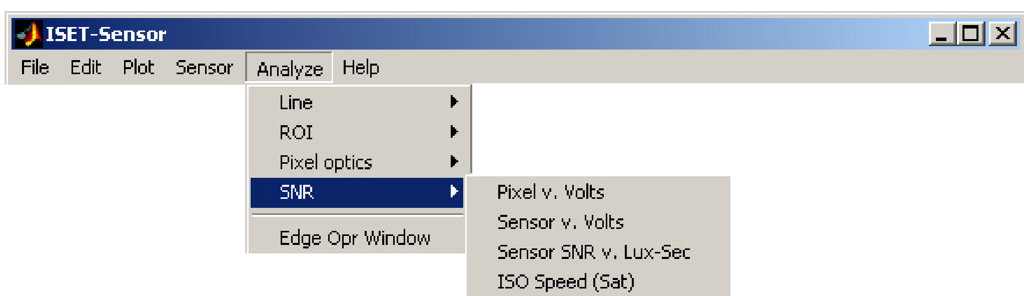
A variety of standard sensor formats can be used. These sensor sizes and resolutions are commonly used in the industry, ranging from ¼ inch to one-inch in the CIF and VGA sub-menus. We recommend performing your computations with a small sensor, matched to the optics, to explore properties of the early stages of the pipeline.





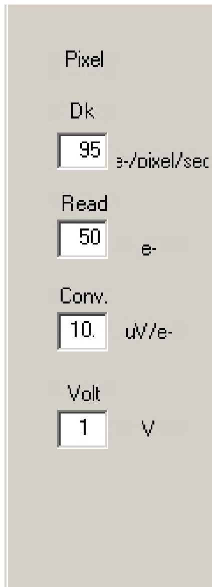


Because of the tunnel in the semiconductor over the photodetector, light is more likely to arrive at the photodetector for pixels in the center of the array compared to pixels at the edge. This phenomenon, which depends on the sensor layers and geometry, is called pixel vignetting. A graph of the relative loss of light from center to periphery for a sensor with any particular number of layers and depth can be obtained from the Analyze pull-down and Pixel-optics sub-menu.

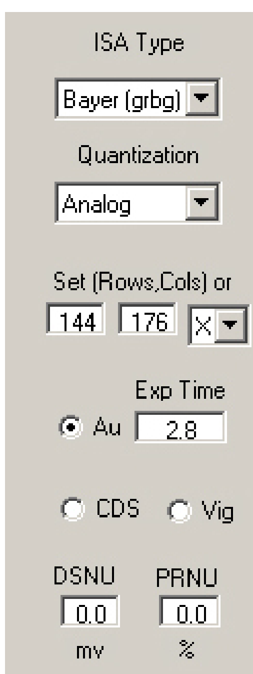


Various characterizations of the Sensor and Pixel SNR can be obtained from the Analyze menu. These include SNR measurements for the pixel and the sensor. Moreover, these measurements can be obtained with respect to voltage or lux-sec of incident illumination assuming a D65 light source. *[Manual slightly out of date here. Pixlel SNR vs. Lux-sec is also calculated, lines introduced between groups.]*

Sensor: Editable boxes



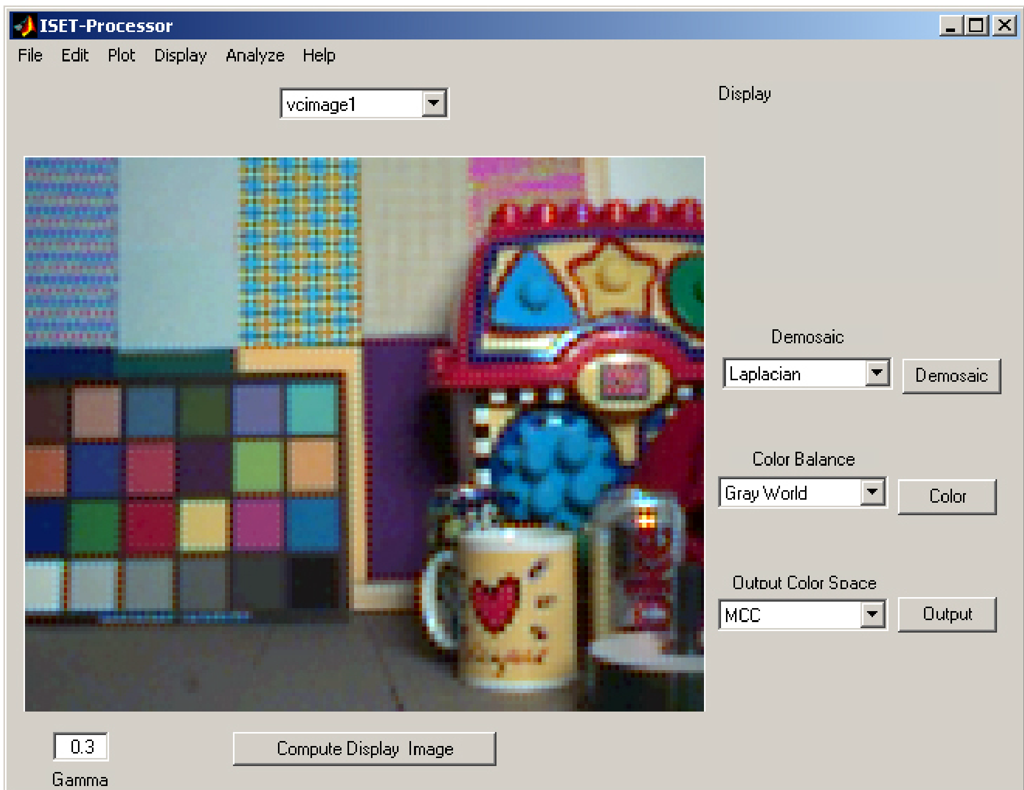
Use the mouse-over feature to read the longer names for these parameters. These are Dark Current, Read Noise, Conversion Gain, and Voltage Swing. All of these values can be set in these editable boxes.

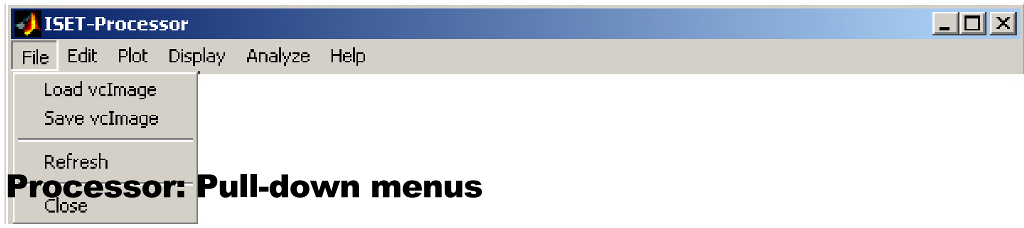


Different types of mosaics GRBG, RGGB, CYYM and Monochrome can be chosen here. The degree of quantization, sensor size are set here. Auto-exposure is turned on or off. Setting an exposure time (in ms) manually turns-off auto-exposure. Correlated double-sampling and pixel-vignetting can be included in the pipeline. Dark-signal non-uniformity levels (standard deviation in millivolts) or photoresponse non-uniformity (standard deviation of the response gain as a percentage of the conversion gain) can be set here.

Processor

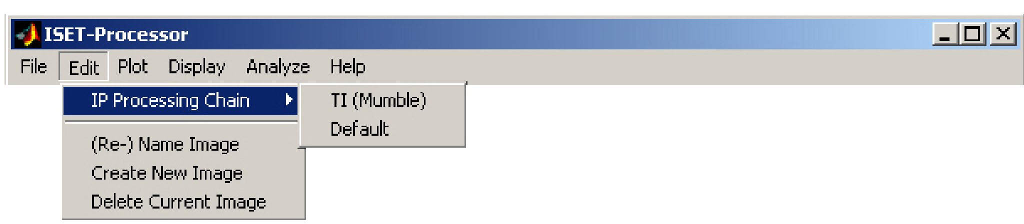
General remarks



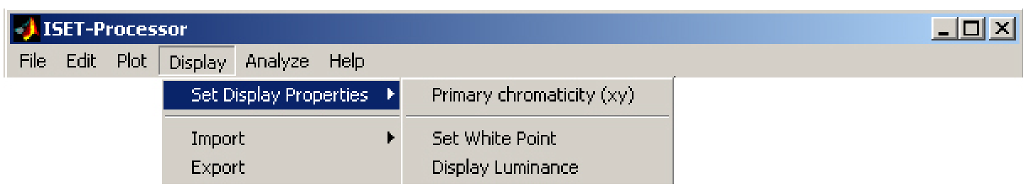


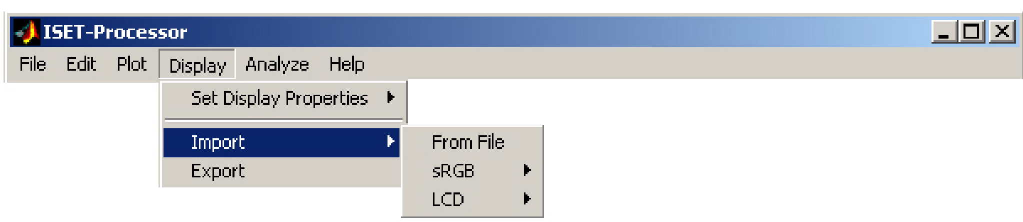
Processor: Pull-down menus

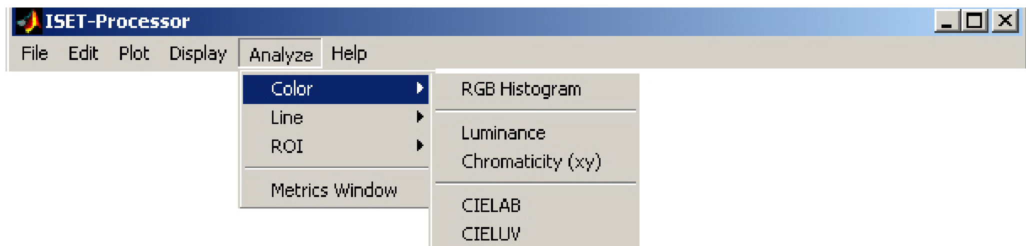
The image displayed in the Processor window is a representation of the processed image, as it would be rendered on a simulated display. You can save and load a rendered image. A red square will appear at the bottom of the Processor window when you change the parameters of the processing or display. You can refresh the representation of the rendered image by selecting the Refresh button. Finally, you can close the window. Again, this does not destroy the information about the current processing and display parameters. When you select the Processor button from the Session window, you will once again see a representation of a the current processed image as it would appear on the current display.

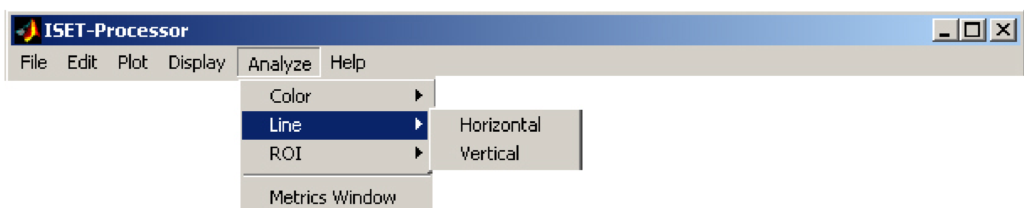


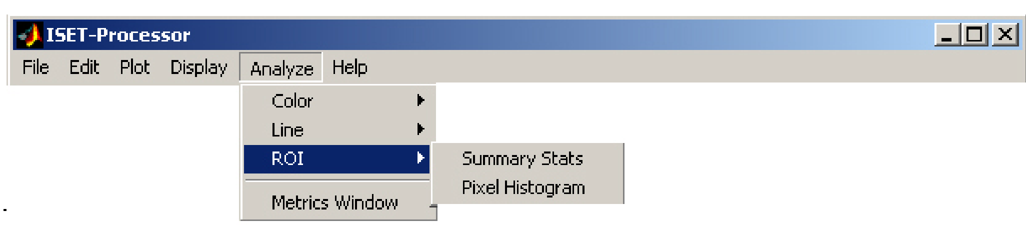

ISET-Processor
File Edit Plot Display Analyze Help
Images
TrueSize


ISET-Processor
File Edit Plot Display Analyze Help
Set Display Properties
Import
Export
Primary chromaticity (xy)
Set White Point
Display Luminance

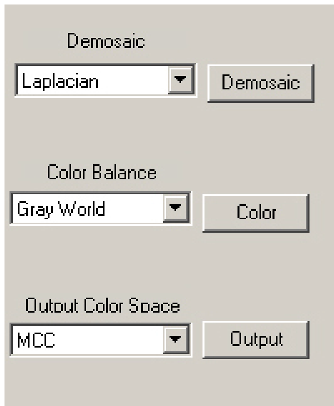

ISET-Processor
File Edit Plot Display Analyze Help
Set Display Properties
Import
Export
From File
sRGB
LCD


ISET-Processor
File Edit Plot Display Analyze Help
Color
Line
ROI
Metrics Window
RGB Histogram
Luminance
Chromaticity (xy)
CIELAB
CIELUV


ISET-Processor
File Edit Plot Display Analyze Help
Color
Line
ROI
Metrics Window
Horizontal
Vertical


ISET-Processor
File Edit Plot Display Analyze Help
Color
Line
ROI
Metrics Window
Summary Stats
Pixel Histogram

Processor: Editable boxes



Explanatory text here

Options for Demosaic are Nearest Neighbor, Bilinear, Laplacian and Adaptive Laplacian

Options for Color Balance are None, Gray World, White World, Bayesian

Appendix

The SCENE database

Matlab Data Conversion Routines

vcXL2vc.m : routine to run inside of Matlab to convert spectral data in Excel spreadsheet into spectral data as a Matlab file (file.mat).

The data should have wavelength in the first column of the Excel spreadsheet and sensitivity (or transmissivity) in the subsequent columns (scaled between 0 and 1)

Example: An Excel spreadsheet for a cyan, yellow, magenta filters

Wavelength (nm)	Cyan (%T)	Yellow (%T)	Magenta (%T)
780.0000	0.6691643	0.9876172	0.9725687
778.8889	0.6628207	0.9883542	0.9718713
777.7778	0.6568444	0.9884193	0.9725651
776.6667	0.6497047	0.9895866	0.9719566
775.5555	0.6430920	0.9885254	0.9713735
774.4445	0.6362457	0.9898154	0.9713428
773.3333	0.6301257	0.9890532	0.9709100
772.2222	0.6228593	0.9891331	0.9707350
771.1111	0.6165825	0.9910802	0.9709256
770.0000	0.6101215	0.9900860	0.9721787
…	…	…	…
…	…	…	…
378.8893	0.1270044	0.2420548	0.5602559

Glossary and Formulae

In which our heros define terms like DSNU, PRNU, Read Noise and other confusing terms.

ISET Programming Guide

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