3DToF System Estimator Tool User Guide

1 Introduction

Time of Flight (ToF) cameras provide a complete depth map of a scene. This information can be used in a myriad of industrial and consumer applications. Modelling a ToF system can be difficult due to the large number of input parameters and system constraints. The ToF system estimator application helps in tuning the input parameters to calculate the optimum operating conditions for the system.

The primary purpose of this document is to explain the features of the ToF system estimator tool which assists in analyzing the performance of a ToF sensor under varied conditions. The document describes the various elements of the GUI. The functionality of each control of the GUI is explained with suitable examples.

2 Intended Audience

This document is targeted towards people who want to

- Analyze a ToF system
- Incorporate ToF systems in their solution
- Check if ToF is a suitable technology for their application

3 Recommended pre-study

- Wikipedia
- System Designer Guide

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4 Quick Start

4.1 INSTALLATION

1. Start installation by running “TI 3D ToF Estimator 2pX.exe”
2. A window asking for administrator privileges will start. Click “Yes”
3. The welcome page is displayed. Click “Next”
4. Read the license agreement and click on “I Agree” to continue

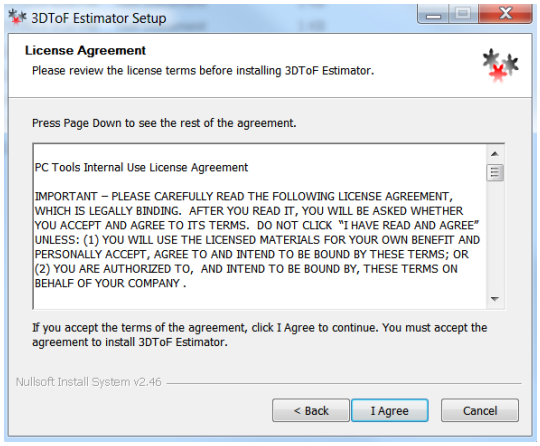

Figure 1: Installer License Page

5. Select whether a Desktop Shortcut or a Start Menu entry is needed. Click “Next” to continue
6. Choose the destination folder using the “Browse” button. Click “Install” to proceed with installation

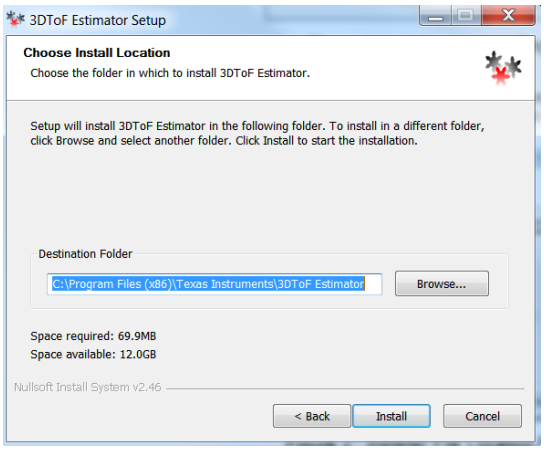

Figure 2 : Installer File Location Page

7. Installer success will now be displayed. Click “Finish” to complete the installation

4.2 UN-INSTALLATION

1. Open the uninstaller: Start Menu->Texas Instruments->TI 3D ToF Estimator ->TI 3D-TOF Estimator Uninstall
2. The application can be un-installed from Control Panel->Programs and Features as well
3. The welcome page is displayed. Click “Next” to continue
4. A confirmation is asked for un-installation. Click on “Uninstall” to continue
5. The uninstaller completes with the below window. Click “Finish” to complete the process

4.3 STARTING THE APPLICATION

1. Open the application “TI 3D ToF Estimator.lnk” from the installation folder, start menu or desktop
2. The application should look like the below figure

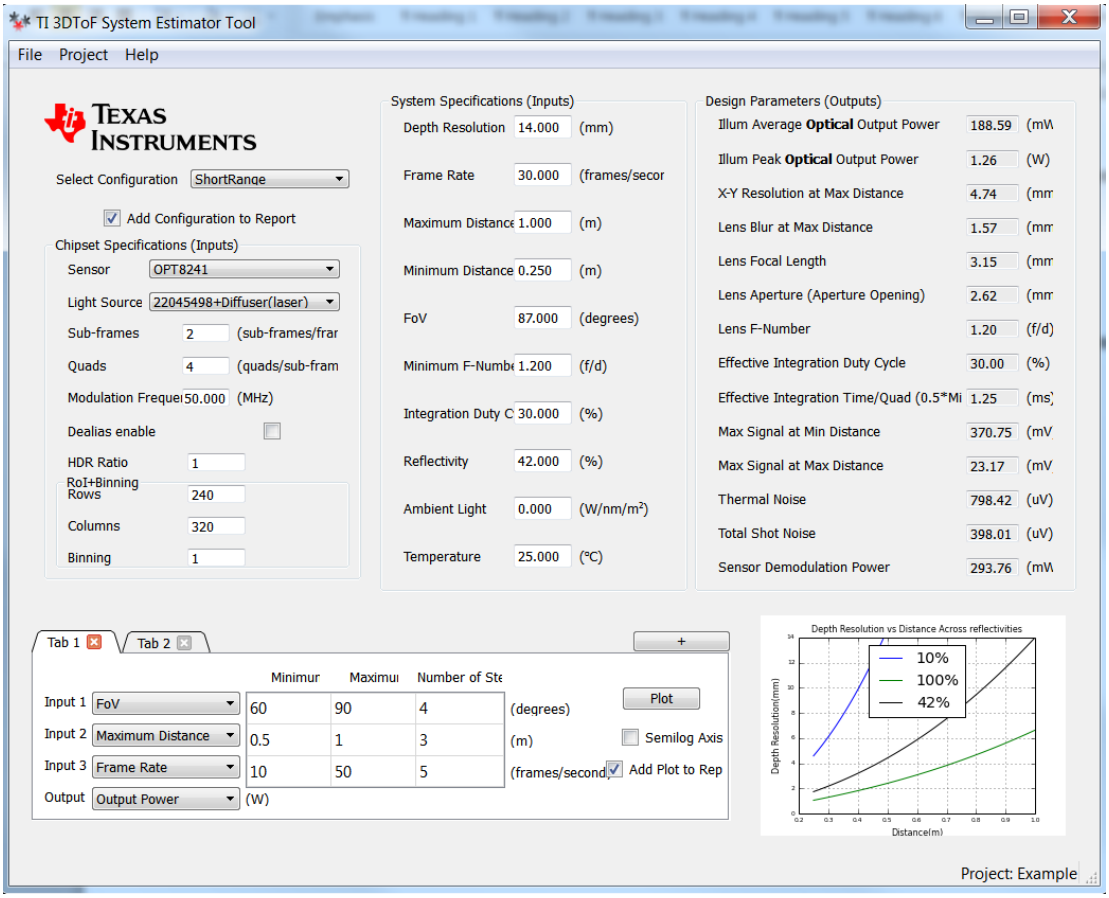

Figure 5: TI 3D TOF Estimator

3. To start the application again, click on the same link as Step 1. Note: the registration process happens only once.

5 GUI Structure

Various parts of the GUI include:

1. Menu Bar
    a. File
        i. New Project: Create a new project
        ii. Open Project: Open an existing project
        iii. Save Project: Save the current project
        iv. Save Project As: Save the current project as a different project
        v. Exit: Close the application
    b. Project
        i. Generate Report: Generate a report consisting of different project parameters and plots
        ii. Manage Configurations: Create, delete, duplicate or modify configurations in the project
        iii. Manage Light Sources: View default light sources and add custom light sources
        iv. Manage Sensors: View default sensors and add custom sensors
    c. Help
        i. About: Version information of the application
        ii. User Guide: Opens the user guide in pdf format in another window
2. Select Configuration: Choose the current configuration to be used. Each configuration has different input parameters and tabs
3. Add Configuration to Report: If checked, the configuration is added to the generated report.
4. Chipset Specifications: Contains parameters pertaining to the chipset – sensor type, light source type, sub-frames, quads, modulation frequency, pixel resolution, demod contrast, filter bandwidth, region of interest and binning.
5. System Specifications: Contains parameters pertaining to the system – depth resolution, frame rate, maximum and minimum distance, field of view, minimum F-number, integration duty cycle, reflectivity, ambient light and temperature.
6. Design Parameters (Outputs): The final design parameters obtained from the inputs given – average and surge optical power, X-Y resolution at maximum distance, lens blur at maximum distance, lens focal length, lens F-number, effective integration duty cycle, effective integration time, maximum voltage at minimum and maximum distance, thermal noise, total shot noise and sensor demodulation power.
7. Plotting Tabs: Gives a sweep across one, two or three different input parameters in a specified range for either output power or depth resolution. Multiple tabs can be present for a particular configuration.
8. Depth Resolution vs. Distance graph: Plots the depth resolution against distances varying from the minimum distance to the maximum distance across different reflectivities.
9. Status Bar: Gives information of the project name and information about saving of a file and report generation. It also provides information about which parameters should be changed when the output goes beyond upper or lower limits.

6 Menu Bar

6.1 FILE

Projects are SDX files and contain data pertaining to the inputs and plotting tab parameters for each configuration. Projects can be managed using the file menu options like “New Project”, “Save Project”, “Save Project As” and “Open Project”. The application can be closed by choosing the “Exit” option.

6.2 PROJECT

6.2.1 Generate Report

A report is a PDF file containing data and plots pertaining to the project. Configurations can be added to a project by selecting the “Add Configuration to Report” check box. Similarly, each plotting tab can be added to a report by selecting the “Add Plot to Report” check box. The report consists of:

1. Project Name
2. Selected Configurations

a. Specifications (Inputs)
b. Design Parameters (Outputs)
c. Depth Resolution vs. Distance Graph
d. Selected tabs
    i. Tab parameters: One, two or three inputs with their minimum, maximum and number of steps and the output
    ii. Plots: Can be either log or semi-log according to whether the “Semilog” check box is checked
    iii. Manage Configurations

A configuration consists of inputs, both chipset and system parameters, along with the plotting tab information. Each project can have multiple configurations. Subsequently, each configuration can have multiple plotting tabs.

Configurations can be made for different environments. For example, short range and long range can be two different configurations with parameters specific to the type of environment. For a short range configuration the maximum distance will be smaller than that of a long range configuration.

Configurations can be managed, i.e., added, deleted or renamed by selecting this menu option.

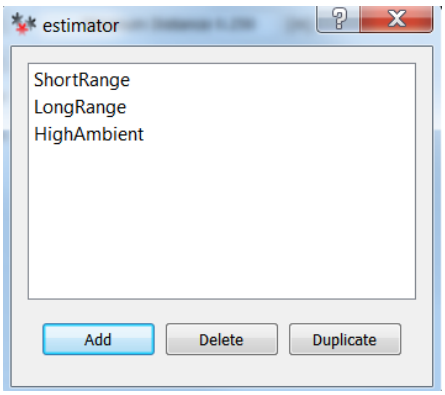

Figure 6: Manage Configurations

A list of configurations is displayed. A configuration can be renamed by double clicking the name. Configurations can be added, deleted or duplicated by clicking the appropriate button.

Once a configuration is modified in this window, the drop down menu of “Select Configuration” also changes.

Note: The current configuration cannot be deleted.

6.2.2 **Manage Light Sources**

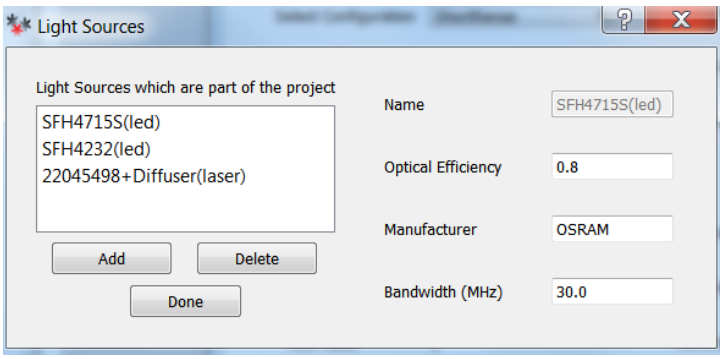

Figure 7: Manage Light Sources

Light sources provide the illumination for the sensor. The only parameter of a light source is bandwidth which is the electrical bandwidth of the light source (in MHz). The bandwidth limits the maximum modulation frequency which can be given to the chipset. Bandwidth can vary from 10 MHz to 200 MHz.

There are three default light sources included with the application:

1. 22045498+Diffuser: Laser with diffuser
2. SFH4232: LED
3. SFH4715S: LED

Parameters for the default light sources cannot be modified by a user. If a new light source with different parameters is required, the user can use the “Add” and “Delete” buttons. The bandwidth can be modified for custom light sources. Custom light sources can be renamed by double clicking and typing the new name.

Once this window is closed or “Done” is clicked, both the default and custom light sources are added to the “Light Source” drop down menu under chipset specifications. Light sources are a part of the project and need to be saved. Opening a project would load the saved data into the “Manage Light Sources” window and the “Light Sources” drop down menu.

6.2.3 Manage Sensors

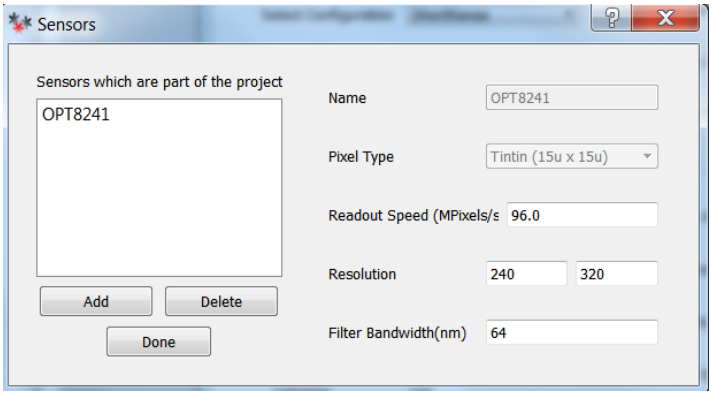

Figure 8: Manage Sensors

The four parameters of a sensor include:

1. Pixel Type: Generation of pixel type with associated pixel pitch
2. Readout Speed: The number of pixels which can be read from the sensor per second (MPixels/s). Maximum is 1000 MPixels/s.
3. Resolution: Number of rows and columns present in the sensor. Maximum is 1000.
4. Filter Bandwidth: Optical bandwidth (in nm). It ranges from 5 nm to 200 nm.

There is only one default sensor included with the application as of now:

1. OPT8241

Parameters for the default sensors cannot be modified by a user. If a new sensor with different parameters is required, the user can use the “Add” and “Delete” buttons. The four parameters mentioned above can be modified for custom sensors. Custom sensors can be renamed by double clicking and typing the new name.

Once this window is closed or “Done” is clicked, both the default and custom sensors are added to the “Sensors” drop down menu under chipset specifications. Sensors are part of the project and need to be saved. Opening a project would load the saved data into the “Manage Sensors” window and the “Sensors” drop down menu.

6.3 HELP

Help consists of two options: About and User Guide. About displays version information about the application and User Guide opens this user guide for reference.

7 Chipset Specifications

Chipset specifications include the following:

1. Sensor: Indicates the sensor for which design parameters have to be calculated. A tool tip over this parameter indicates the pixel pitch, responsivity and fill factor for that particular sensor. Whenever the sensor is changed various parameters are reset to their default values:
    a. Sub-frames: 2
    b. Quads: 4
    c. Rows: Maximum rows for the sensor
    d. Columns: Maximum columns for the sensor
    e. Binning: 1

    Changing the sensor also changes Pixel Resolution, AC Contrast and Filter Bandwidth parameters. These three parameters cannot be modified by the user and are specific to a sensor
2. Light Source: Indicates the light source being used. As discussed in Section 6.3.2 these light sources can be either default or custom.
3. Sub-frames: Smallest unit of a frame that has complete depth information. Refer to the System Design Guide
4. Quads: Refer to the System Design Guide
5. Modulation Frequency: The frequency of illumination modulation and the sensor demodulation.
6. Pixel Resolution: Number of rows x Number of columns of the sensor
7. HDR (High Dynamic Range) ratio: Ratio of integration duty cycle in a normal frame to integration duty cycle in a HDR frame. Every alternate frame will be a normal frame and the other frames will be HDR frames. The depth resolution shown in the graphs will be the better of the two resolutions. In the system, if the HDR + normal frames are combined to form a single frame, the actual frame rate will be half of the displayed frame rate.
8. Dealias en : Enable dealiasing using multiple modulation frequencies. The modulation frequency field has to be filled with the mean of the two frequencies used. When dealiasing is used, the minimum number of quads is limited to 6 for OPT8241 and 8 for OPT8320. Special note for OPT8320 - Alternate frames run different modulation frequencies to achieve de-aliasing and the data of the two successive frames is combined and given out. Therefore, it is equivalent to increasing the quads to 8. In practice it is possible to use different sub-frames for base and supplementary frames and achieve lower number of effective quads. But this optimization is not implemented in the system estimator.
9. Filter Bandwidth: Optical filter bandwidth in nanometers.
10. Region of Interest (RoI) + Binning
    a. Rows: Number of rows in the region of interest
    b. Columns: Number of columns in the region of interest
    c. Binning: Number of pixels to be binned into one pixel

8 System Specifications

System specifications include the following:

1. Depth Resolution: The depth resolution in millimeters repeatability at 1σ repeatability
2. Frame Rate: Number of frames per second captured from the sensor
3. Maximum Distance: Greatest distance in meters up to which an object can be detected
4. Minimum Distance: Least distance in meters for which an object can be detected
5. Field of View (FoV): The diagonal field of view in degrees
6. Minimum F-number: The minimum F-number of the lens. This parameter decides the aperture F-number (=f/D)
7. Integration Duty Cycle: Ratio of duration of time during which light is collected by the sensor to the total frame time in %
8. Reflectivity: Reflectivity of an object in the scene in %
9. Ambient Light: Power in W/nm/m^2 in the optical filter range
10. Temperature: Ambient Temperature in ^{o}C

9 Design Parameters

These are the outputs of the estimator indicating power, optical and other requirements of the system.

1. Illum Average Optical Output Power: The average optical power in Watts required for the system
2. Illum Surge Optical Output Power: The peak optical power in Watts required for the system
3. X-Y Resolution at Max Distance: The height/width of each pixel's view on the object.
4. Lens Blur at Max Distance: Blur due to lens limitations.
5. Lens Focal Length: The focal length in millimeters of the lens to be used for the system
6. Lens Aperture: Lens diameter that participates in the collection of light.
7. Lens F-number: Focal length / Lens Diameter
8. Distance of Perfect Focus: The distance at which when an object is placed, the image is formed exactly on the sensor plane. At all other distances, the image is slightly out of focus.
9. Effective Integration Duty Cycle: Ratio of integration time to the total frame time.
10. Effective Integration Time/Quad: Total integration time per quad.
11. Max Voltage Generated at Min Distance: Voltage swing at the output of a pixel at minimum distance
12. Max Voltage Generated at Max Distance: Voltage swing at the output of a pixel at maximum distance
13. Thermal Noise: Reset noise of the pixels.
14. Total Shot Noise: Shot noise due to ambient light and signal light.
15. Sensor Demodulation Power: Total power consumed by the pixels for demodulation.

Each of the output controls has a lower and upper cutoff. If they are reached the output turns red. A message in the status bar (bottom left of the screen) will display which input parameters to alter in order to bring the system to a stable state.

There is a special relationship between minimum F number (input) and lens F number (output). When these two parameters don't match, they become orange. A message in the status bar will indicate what value needs to be changed. The same effect happens when the Integration Duty Cycle input does not match the Effective Integration Duty Cycle output. Even when minimum distance > maximum distance, the same effect occurs.

10 Plotting Tabs

Plotting tabs are used to create plots sweeping across one, two or three different input parameters. A configuration can have one or more plotting tabs. Tabs can be added by pressing the "+" button at the top right corner of the tab widget. Individual tabs can be deleted by clicking on the close button next to each tab name.

The operation of how the plotting occurs is best explained with the help of an example. In the above figure, "Input 1" is the "FoV", "Input 2" is the "Maximum Distance" and "Input 3" is the "Frame Rate". The output is the "Output Power of the system". The plots are such that "Input 1" remains constant in each sub-plot, each line in a sub-plot is for a particular value of "Input 2" and the X-axis is "Input 3". Once the "Plot" button is clicked the following plot will be displayed:

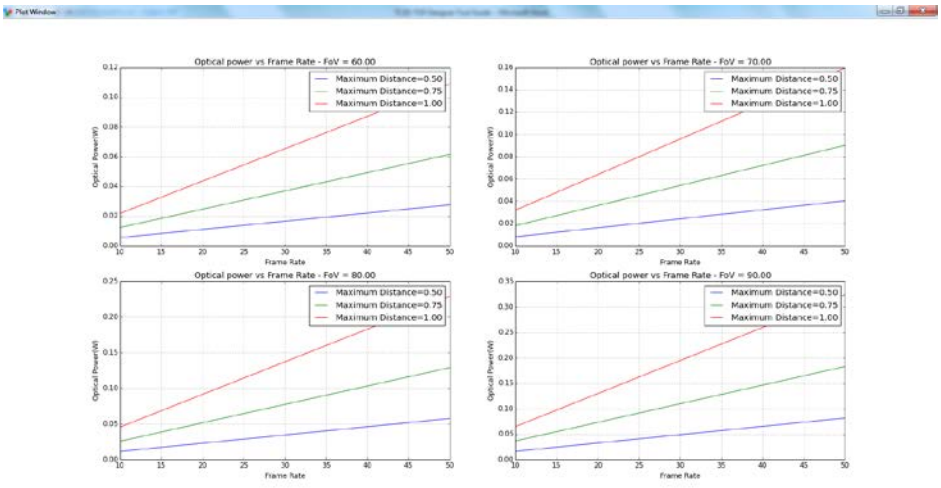

Figure 9: Plots with Normal Axis

It is possible to choose the "None" option for any of the inputs. "None" would indicate that no sweep occurs over that parameter. For example, if the second input ("Maximum Distance" in this case) was set to "None", the result

would be as in Figure 10. Similarly, if two inputs are made “None” (“Maximum Distance” and “Frame Rate”) the plot would be swept across only one parameter. This is shown in Figure 11.

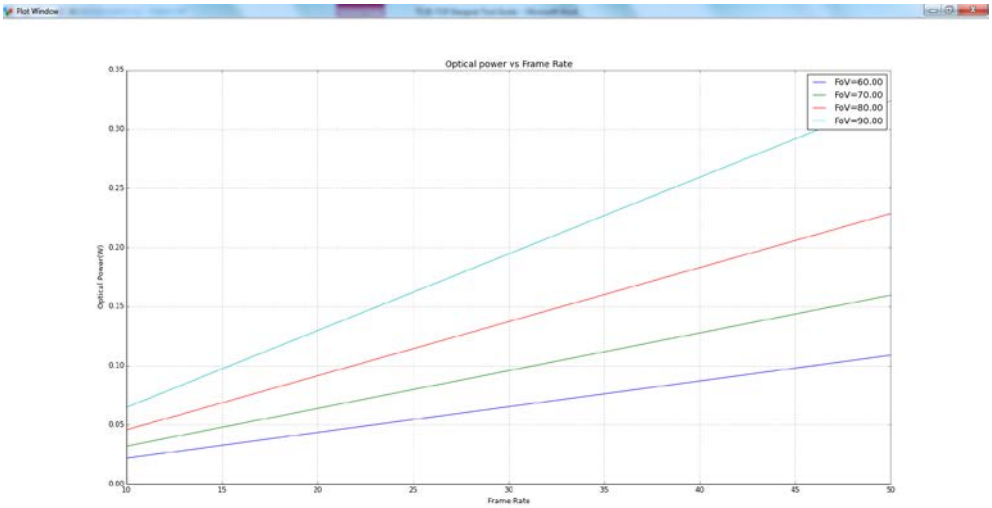

Figure 10: Plot with one "None" Option

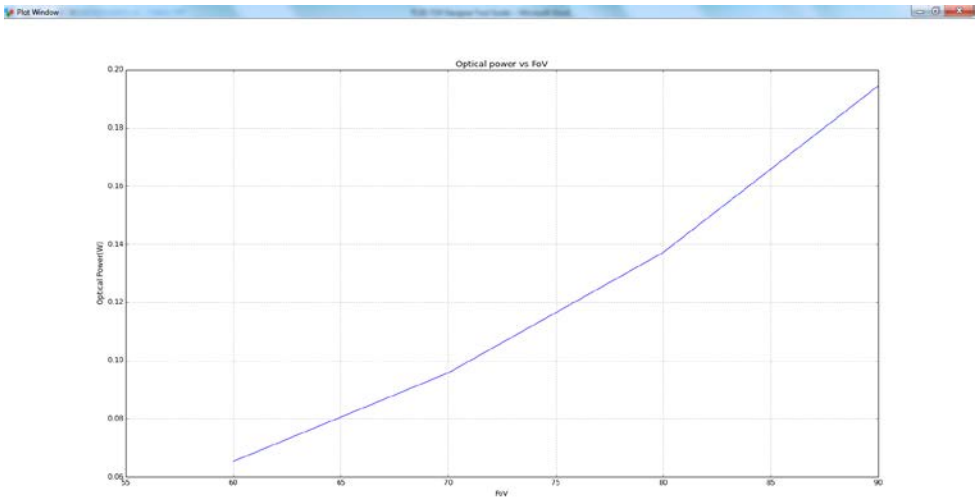

Figure 11: Plot with two "None" Options

It is also possible to choose the output. The output can be either “Output Power” or “Depth Resolution”. Figure 12 shows an example plot for “Depth Resolution”.

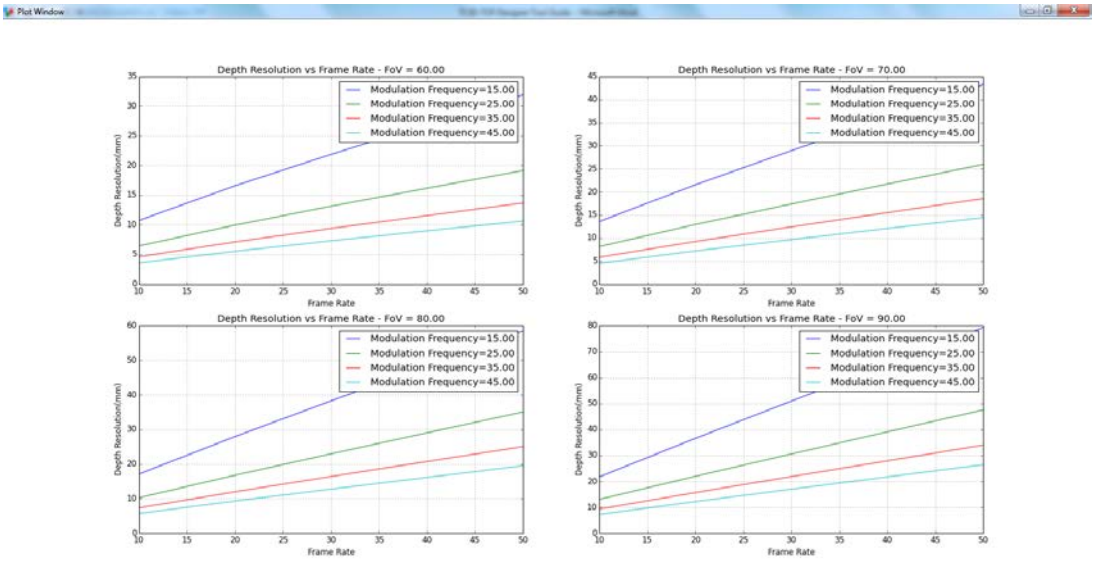

Figure 12: Plots for Depth Resolution

If the “semilog” option is checked the Y-axis of all plots becomes logarithmic as shown below.

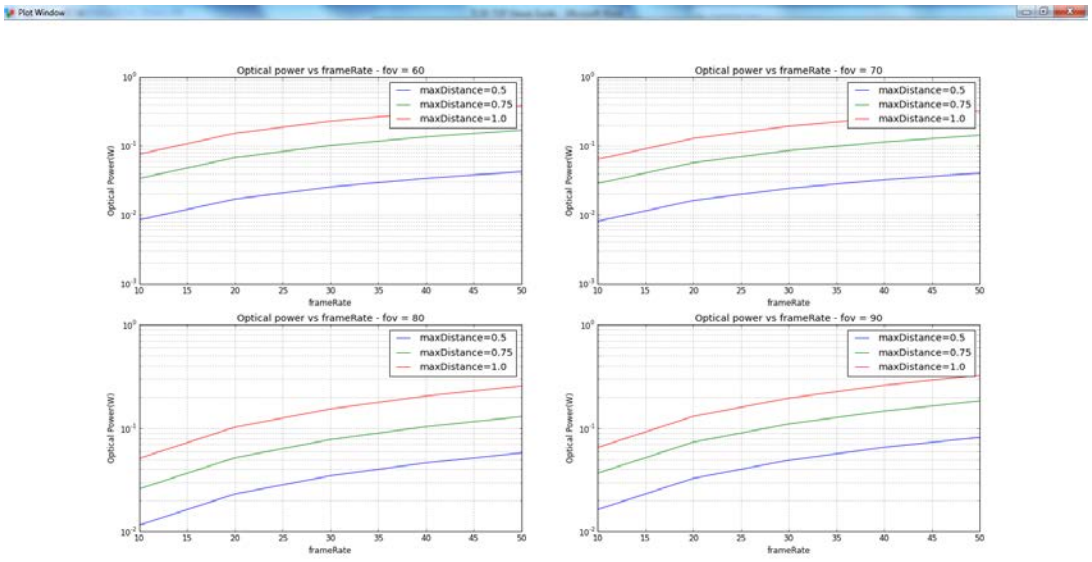

Figure 13: Plots with Semilog Y-axis

11 Depth Resolution vs. Distance Plot

This plot resides in the bottom right corner of the GUI. The X-axis varies from the minimum distance to the maximum distance (system specifications) and the Y-axis is the depth resolution at a particular distance. Every time an input is changed this plot is updated.

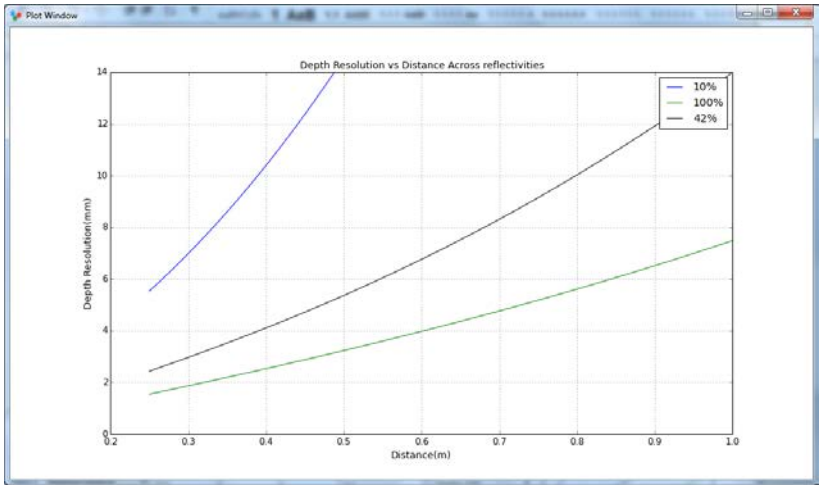

Figure 14: Depth Resolution vs. Distance

The three lines in the plot indicate the depth resolution for different reflectivities. The blue line is for reflectivity of 10%, black for reflectivity of 100% and green for the reflectivity indicated in the system specifications (in this case 42%).

Double click to open this plot in a separate window.

Note: If a square is indicated in either the normal plotting tab plots or the depth resolution plot it indicates pixel saturation, i.e., the pixel has reached its maximum voltage.

12 Status Bar

The status is split into two. The right half always displays the project name. If the project name is “Example” it means that the current project is default and needs to be saved into a file. The name of the file indicates the project name.

The left half gives status information about whether a file has been saved with the “File has been Saved” message and whether a report has been generated with the “Report Generated” message. These messages are temporary.

The status bar also gives information about correcting the system when inputs go beyond limits. These include:

1. Integration Duty Cycle (System Specification) doesn’t match the Effective Integration Duty Cycle (Design Parameter)
2. Minimum F-Number (System Specification) doesn’t match the Lens F-Number (Design Parameter)
3. Minimum Distance becomes greater than Maximum Distance

13 Input Control

The application has many input text box controls. Some of the inputs have a tooltip giving more information about the input. The input is limited between a minimum and maximum value. The below table indicates the default, minimum and maximum values of all the input parameters.

Table 1: Input Parameter Properties

	Units	Default	Minimum	Maximum
Sub-frames	sub-frames/frame	2	1	32
Quads	quads/sub-frame	4	4	6
Modulation Frequency	MHz	50	5	Min(90, 80% of light source bandwidth)
Rows	None	Rows of sensor	1	Rows of sensor
Columns	None	Columns of sensor	1	Columns of sensor
Binning	None	1	1	Min(Rows of sensor, Columns of sensor)
HDR Ratio	None	1	1	128
Depth Resolution	mm	14	0.1	1000
Frame Rate	frames/second	30	0.001	5000
Maximum Distance	m	1	0.015 or Minimum Distance (whichever is greater)	1000
Minimum Distance	m	0.25	0.015	1000 or Maximum Distance (whichever is smaller)
FoV	None	87	1	120
Minimum F-number	None	1	1	10
Integration Duty Cycle	%	30	0.001	100
Reflectivity	%	42	0.001	100
Ambient Light	$W/nm/m^2$	0	0	1
Temperature	^oC	25	-20	70

By typing a value into the text box and pressing enter, the parameter changes and the outputs are updated

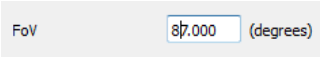

Figure 15: Key Control for Inputs

Fine and coarse control is also possible. By placing the cursor in the text box and pressing the up and down key, the value changes in steps of ten. For example let the value in the text box be 87.000. If the cursor is placed to the right of 8 and the up key is pressed, the value changes to 97.000. Similarly, if the down key is pressed, the value is changed to 77.000. Similar operations can be performed on all the digits, even the fractional part. To move between the digits, use the left and right keys.