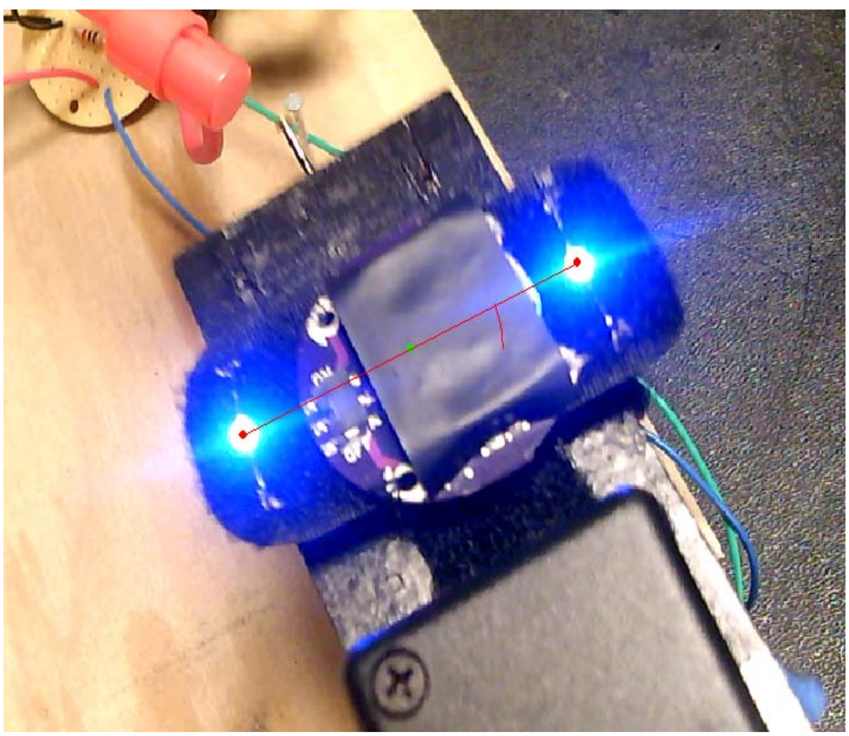
THE GEORGE WASHINGTON UNIVERSITY

Clinical Tremor Analysis Software

User's Manual



Last updated: 4/19/2014

Contents

I. Introduction

Welcome!

If you are reading this documentation, you are involved in the tremor project in Dr. Danoff's lab at the George Washington University. This project was initially suggested by Dr. Danoff for a senior design project under the supervision of Dr. Nagel in SEAS. The students involved in this project were Hailey Cunningham, Justin Lee, and Anne Myung. The goal of this project was to develop a new LED based technique to examine features of physiological tremors. Much of the documentation on how the system was built and evaluated are found in our Final Project Report and "Testing of a Clinical Tremor Analysis System," both which can be obtained from Dr. Nagel and SEAS.

This documentation serves chiefly as a user's manual for the program. As the program is still evolving, many aspects of this manual will change. The program was written in LabVIEW 2010, Student Edition. It uses Service Pack 1. Specifications on the computer used to write it are as follows:

Brand/Model	Sony VAIO Laptop
Processor	Intel® Core i5-2430 M CPU @ 2.40GHz
RAM	4.00 GB
Operating System	Windows 7 Ultimate with Service Pack 1
System type	64-bit OS

NI Vision needs to be installed as a component to LabVIEW.

This program is designed to be used with the LED strap. For more information regarding the LED strap, please refer to the Final Design Report.

Should any questions arise about program usage, please email Justin Lee at <justinlee.gwu@gmail.com>.

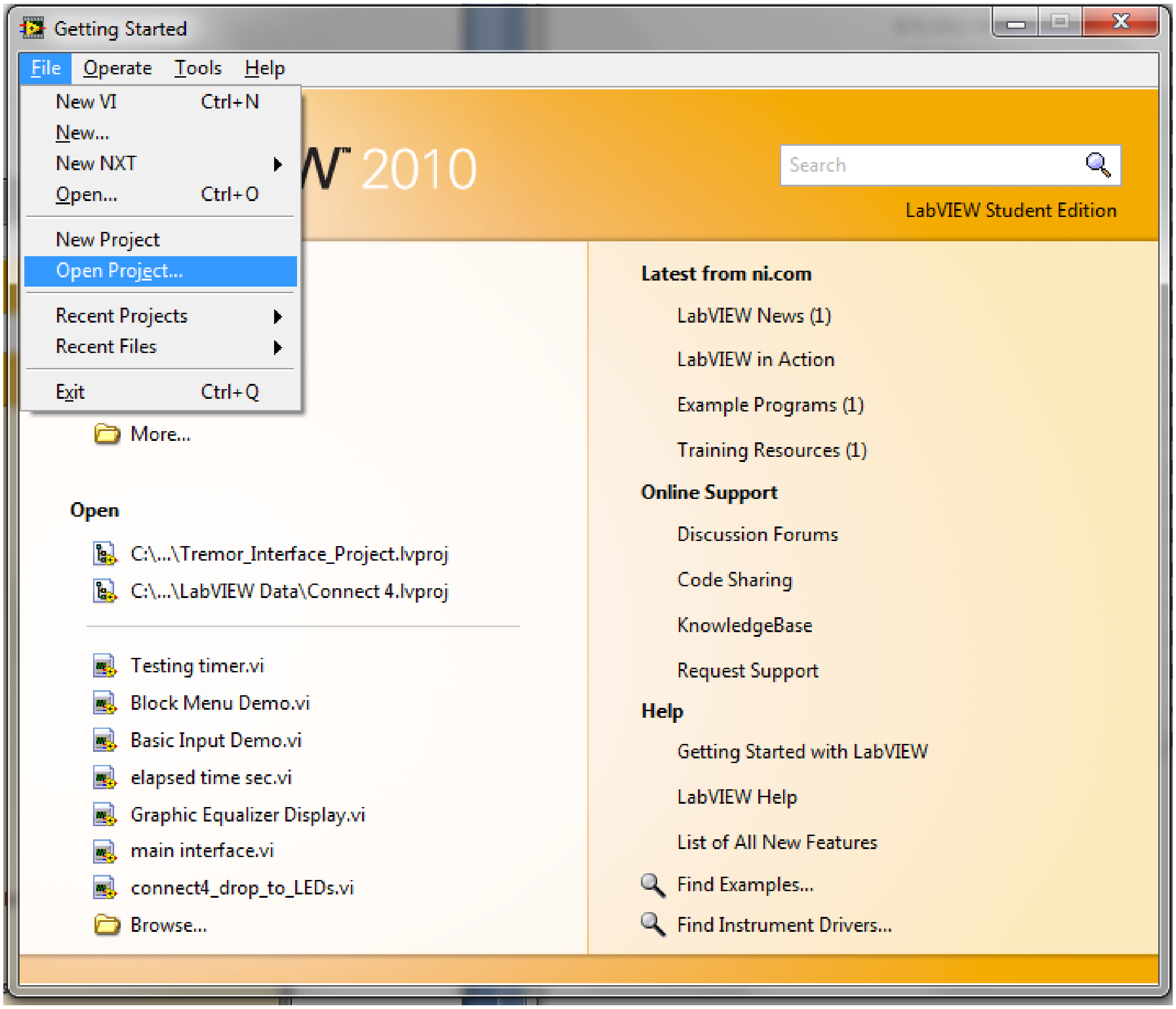
Thanks,
Justin Lee

II. Opening and closing the program library

The entire program can be found in a "project," having the file extension .lvproj. A project is a library of all user created .vi's associated with the program.

The project can be found by either finding it on disk or by opening it through LabVIEW. This documentation will cover finding the library through LabVIEW. Opening up LabVIEW should take you to this screen:

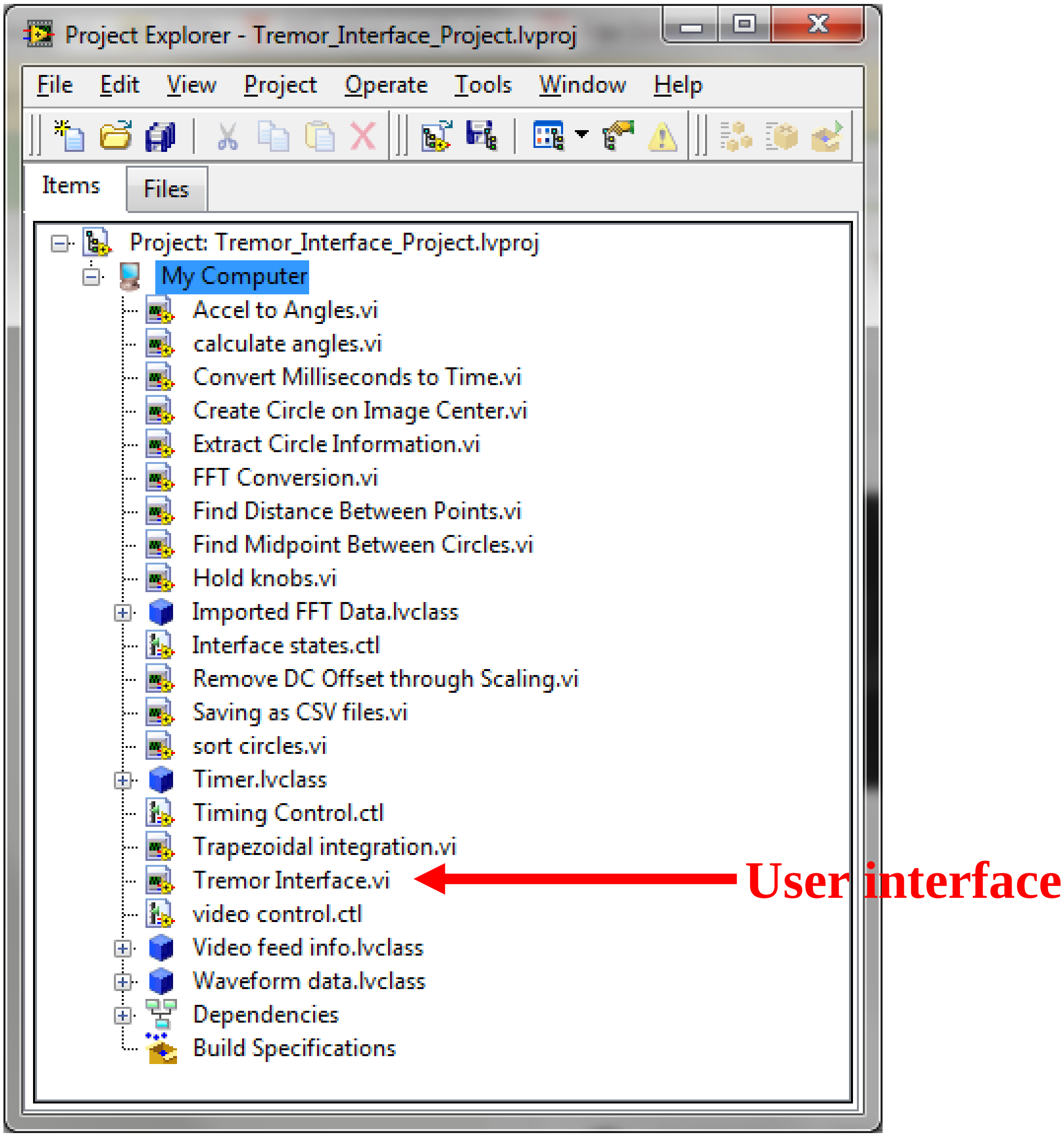
Click "File" and then click "Open Project":



From here select the pertinent .lvproj file. Unless it was changed, it should be called "Tremor_Interface_Project.lvproj."

III. Navigating the project directory

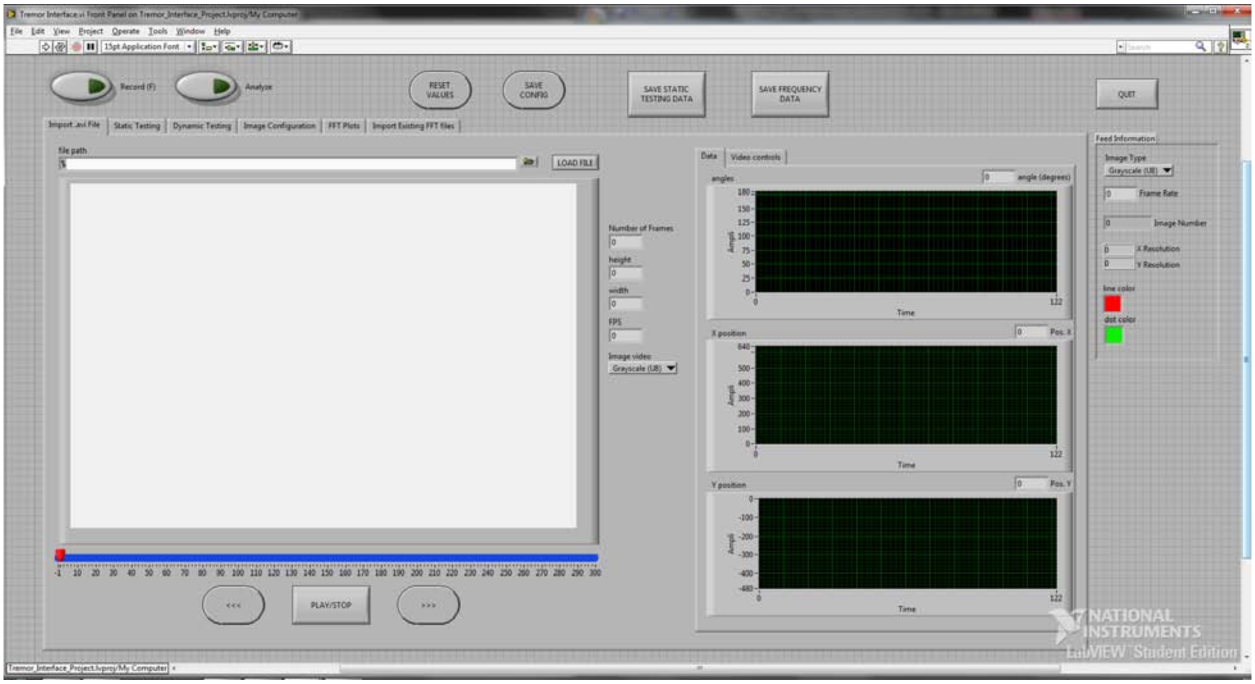
The project directory, when opened, should look like this:



The only .vi that you will need is "Tremor Interface.vi." The rest are low level VI's designed to either carry out data extraction or perform data manipulation and <u>should not</u> be altered unless the user knows what he is doing. This will open up the main user interface.

IV. User Interface Front Panel

Clicking on the “Tremor Interface.vi” will bring up a window like this:

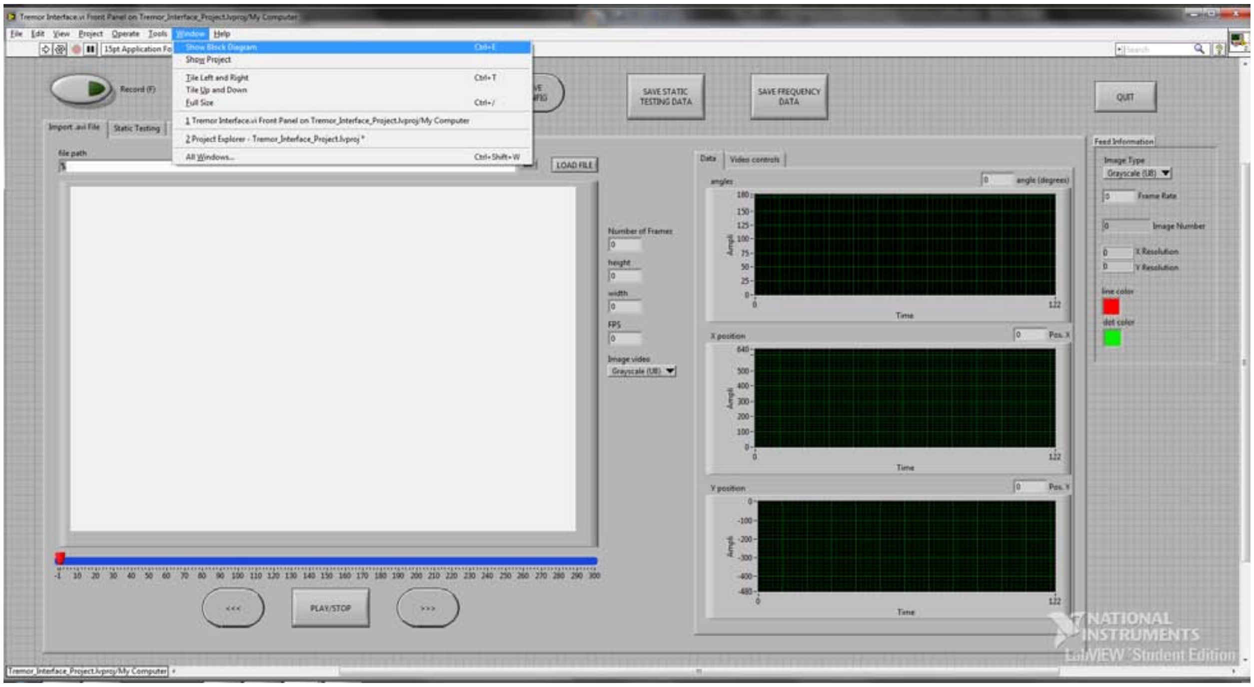


This screen, the user interface, is known as the Front Panel. The user interacts with the program by clicking on icons within the screen.

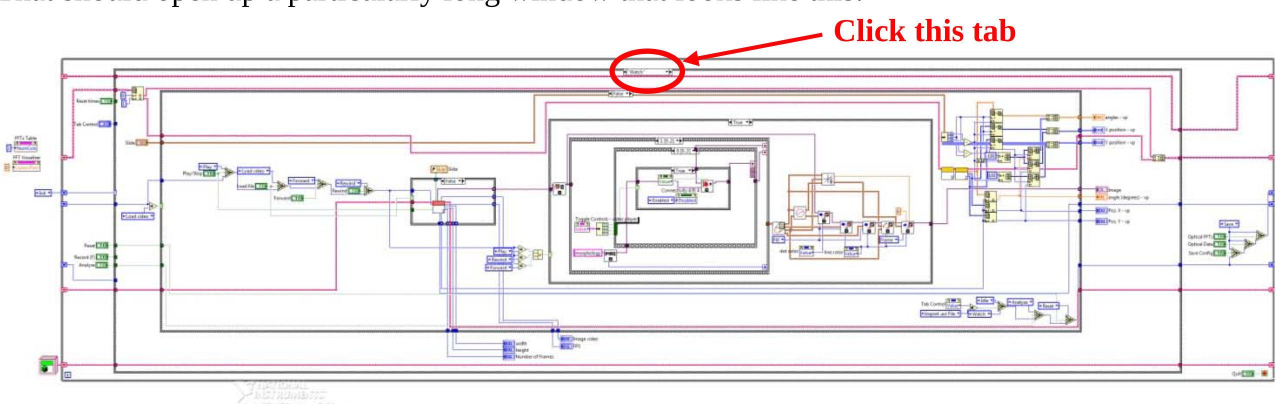
It may have to be resized to fit monitors of different resolutions. Before attempting to use the .vi however, make sure that it is configured with the appropriate camera.

IV.1. Configuring the camera

To configure the camera, go to “Window” on the menu bar and click “Block Diagram:”

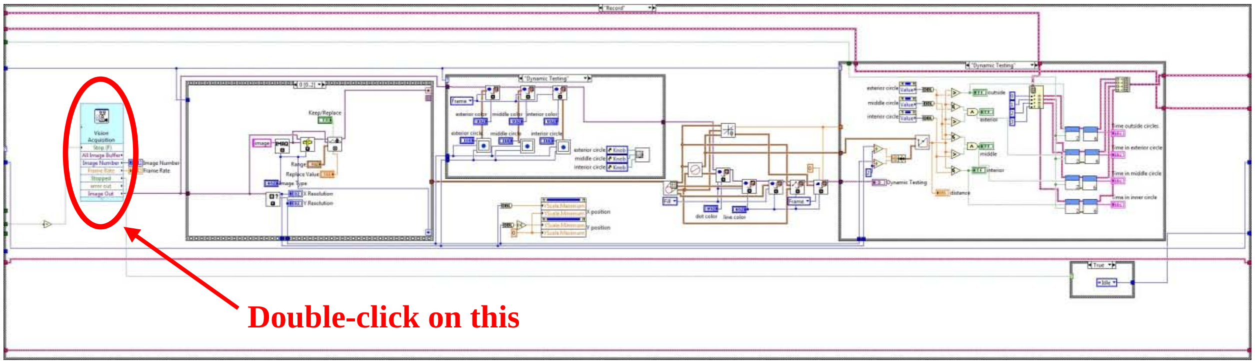


That should open up a particularly long window that looks like this:



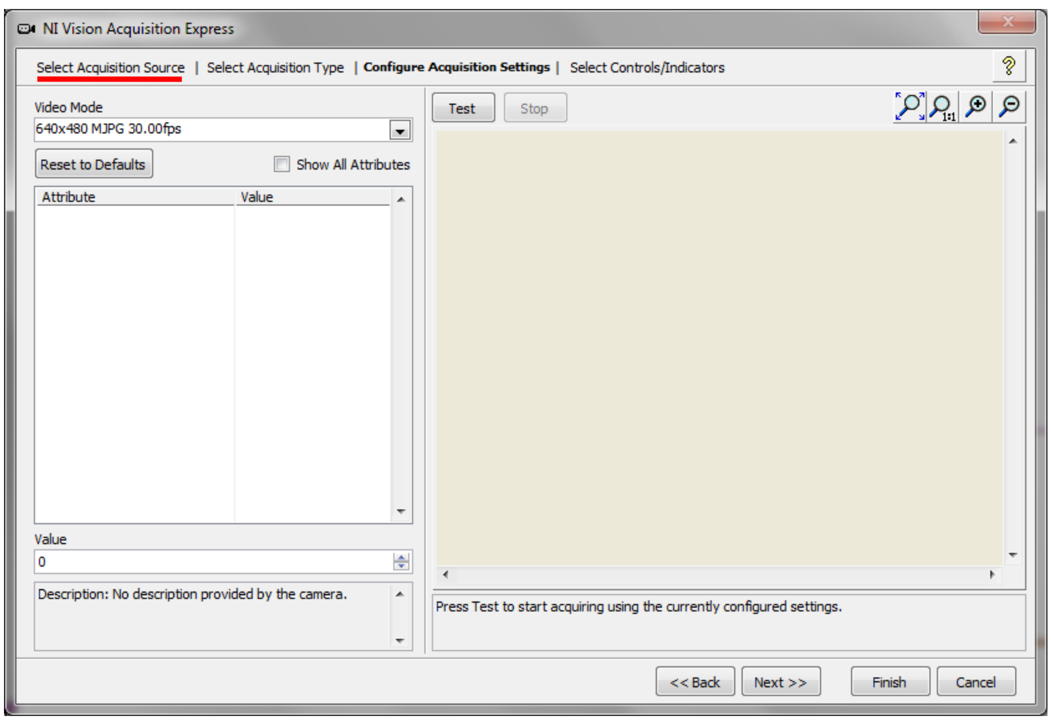
Click on the tab that is circled in the image above and then click on “Record” in the drop-down box.

That should switch the diagram inside the case selector box into this:

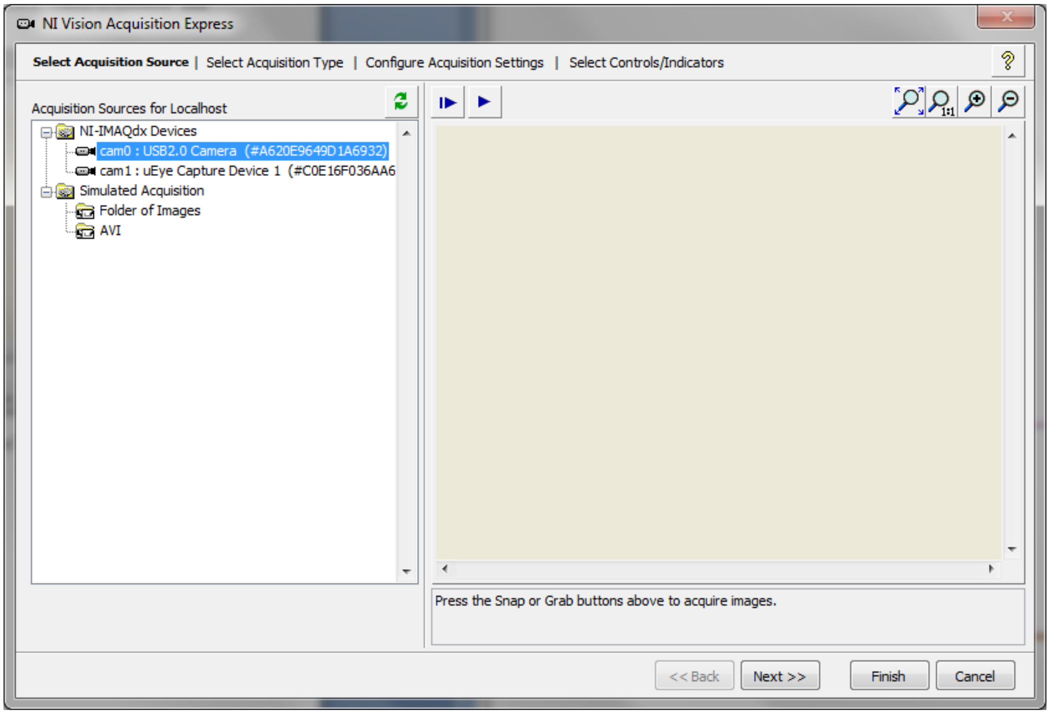


Go to the left side of the box and double click on the "Vision Acquisition" box. That should open up a pop-up screen, as shown in the following image.

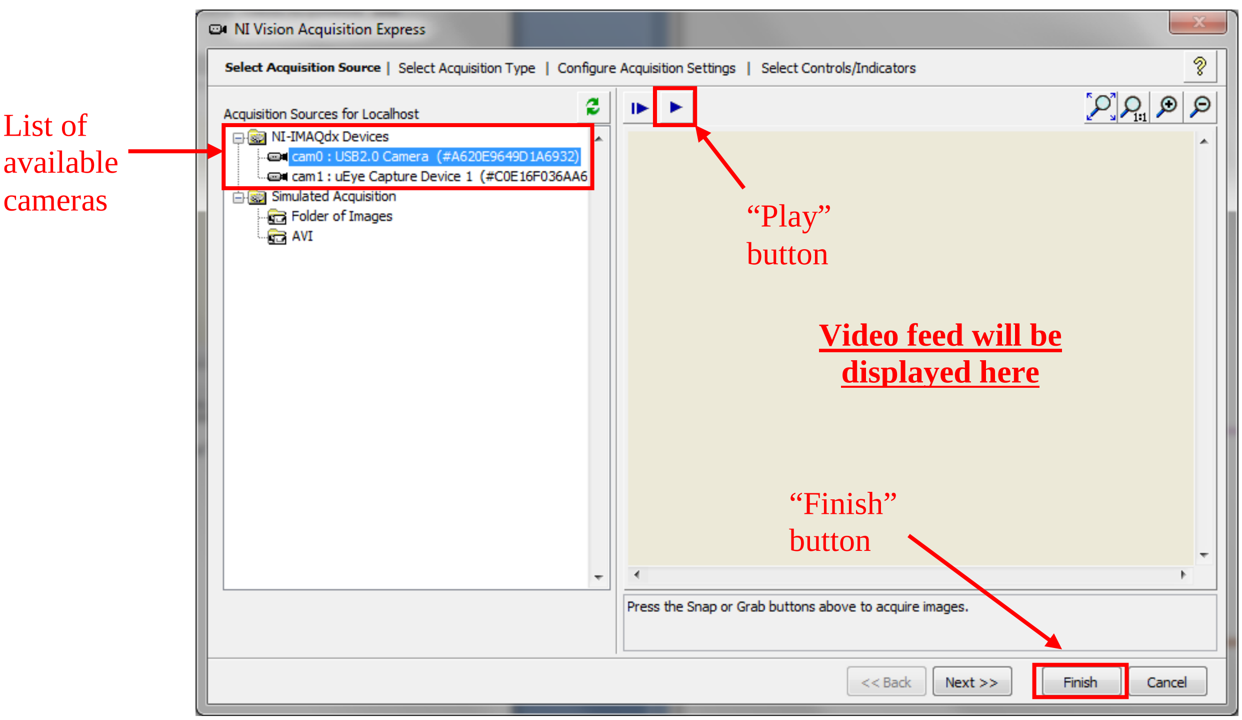
Double click on the icon that is circled in red above. It will be called "Vision Acquisition" and will open up a panel that looks like this:



Press “<< Back” until you are at the “Select Acquisition Source” tab. The screen should look like this:

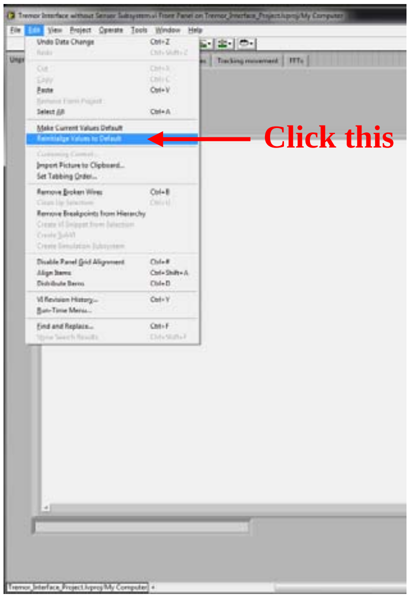


Select the pertinent camera source under the “Ni-DAQdx Devices” folder. To test this camera, press the “play” button. If you are satisfied with your choice, press “Finish:”

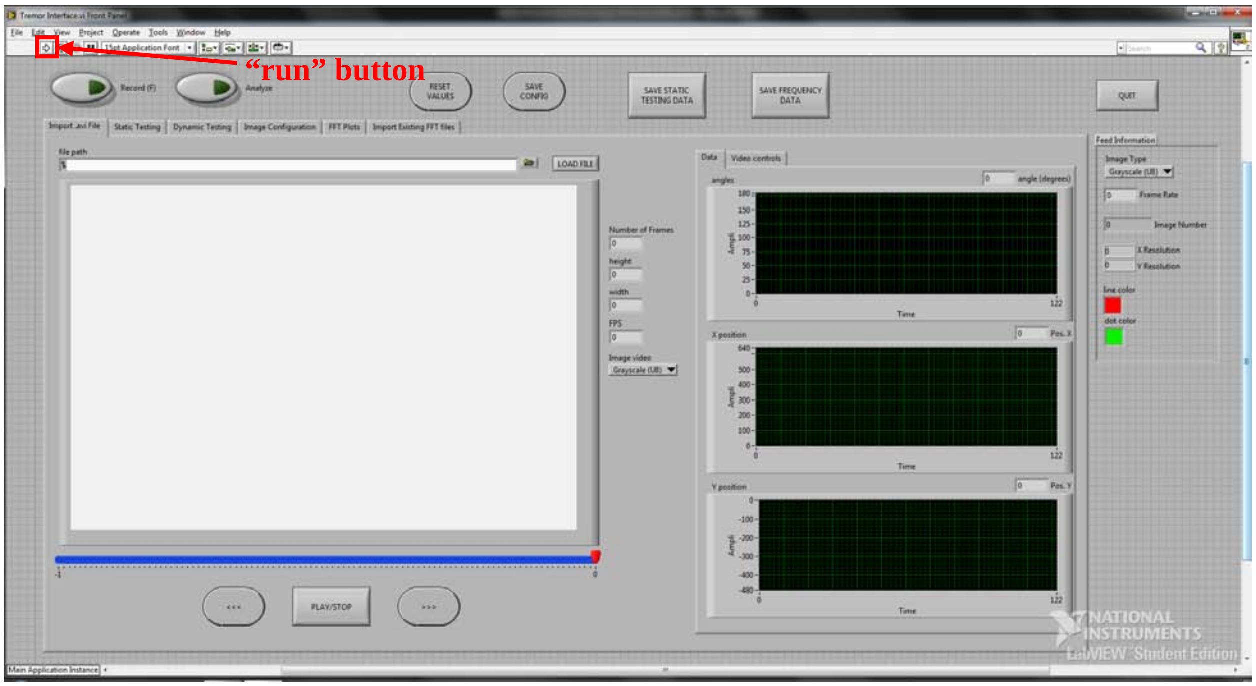


IV.2. Starting the program

Return to the Front Panel. Before you begin collecting data, reinitialize the .vi. To do that, click on “Edit” from the menu bar and then click on “Reinitialize values to default:”



Once all values are reinitialized, press the “run” button:

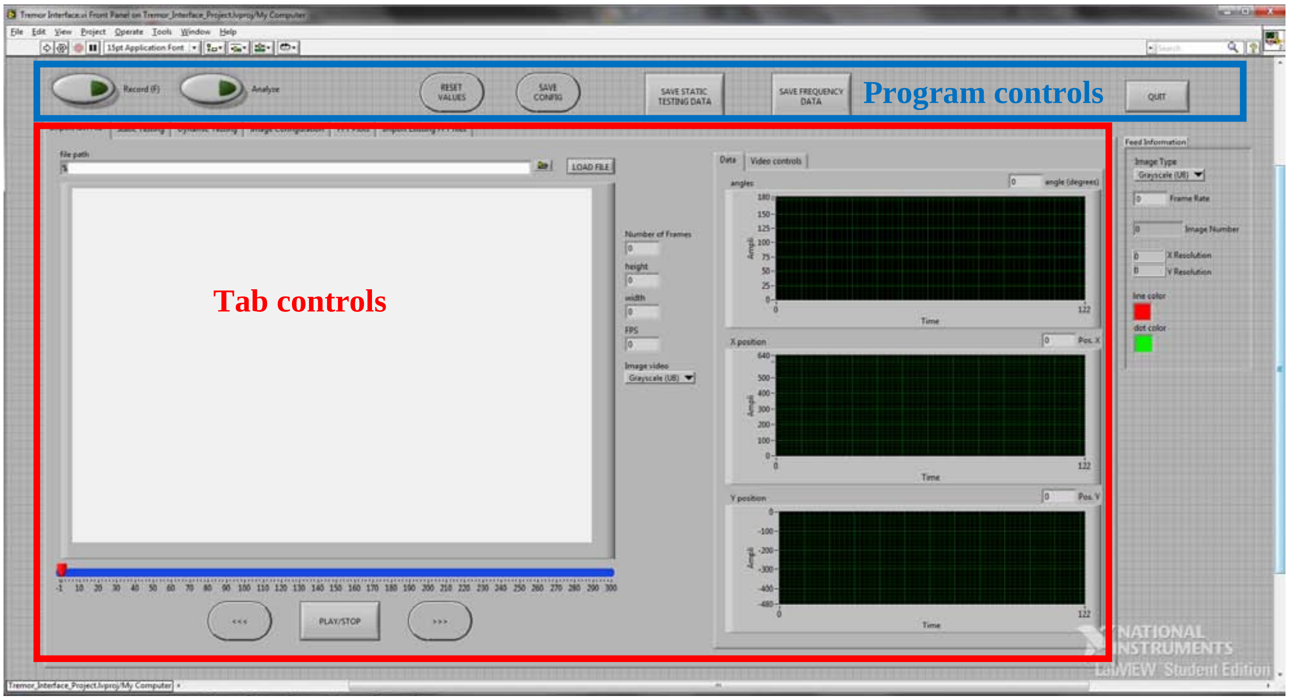


Section V. will describe how the functions within each tab on the Front panel are used. They can be found in the headings:

V.*Tab #.* Tabs – *Name of Tab* - Usage

IV.3. Program control descriptions

The front panel is split up between a large portion of the screen with tabs in the center and various buttons that control the entire program on top:

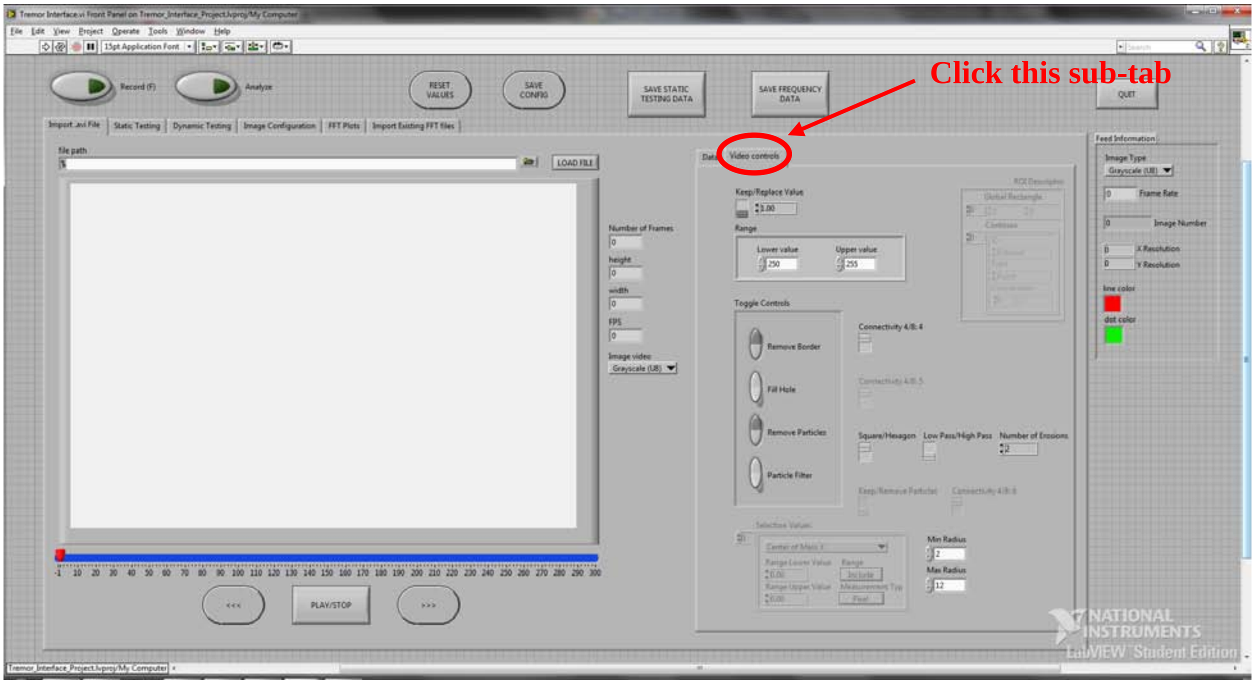


The user is able to click on the tabs in order to cycle through various options that the program offers for analyzing video feed and data. Those will be described in other sections in this documentation. A description of the program controls are as follows (from left to right):

- **Record –** turns on the selected camera for video feed analysis and starts the generation of waveform data
    - Use with “Static Testing” and “Dynamic Testing” tabs only
- **Analyze –** transforms waveform data obtained from a configured camera or imported .avi file into frequency information
    - Automatically brings up “FFT Plots” tab when clicked
- **Reset values –** resets all charts, fields, indicators and figures to default value
    - Make sure to desired waveforms or settings before clicking
- **Save config –** saves the current configuration settings for both camera and imported .avi video analysis to a local .xml file
- **Save static testing data –** Saves waveforms generated from either static testing or from an imported .avi file depending on whether “Import .avi File” or “Static Testing” tab is currently open into an .xlsx file
- **Save frequency data –** Saves the plots that are displayed on the “FFT Plots” tab into an .xlsx file
- **Quit –** Exits the program

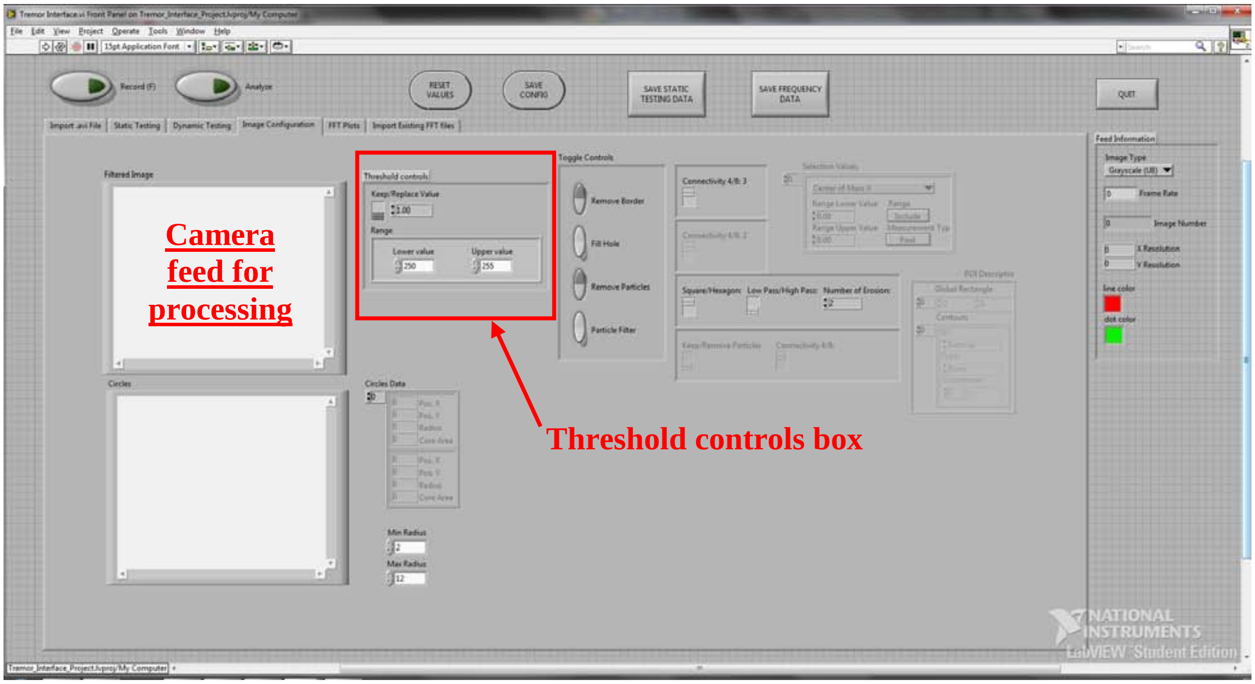
IV.4. Image Configuration

Controls to configure a video feed, whether it is live from a webcam or imported from an .avi file, can be found in both the “Image Configuration” tab and the “Video Controls” sub-tab under “Import .avi file.” The sub-tab “Video Controls” can be found by clicking on the “Import .avi file” tab and navigating to the right side of the screen where the sub-tab is located:



It will be noted that the sub-tab controls the image analysis for the imported .avi files and the “Image Configuration” tab controls the image analysis for the camera feed.

Explanation of a lot of the features in this tab is outside of the scope of this documentation. Users are encouraged to consult the NI Vision help file or a reference textbook on image processing. The "Image Configuration" tab takes the user to a screen shown below:



The screen above is for the "Image Configuration" tab. The controls look the exact same for the ones in the "Video controls" sub-tab.

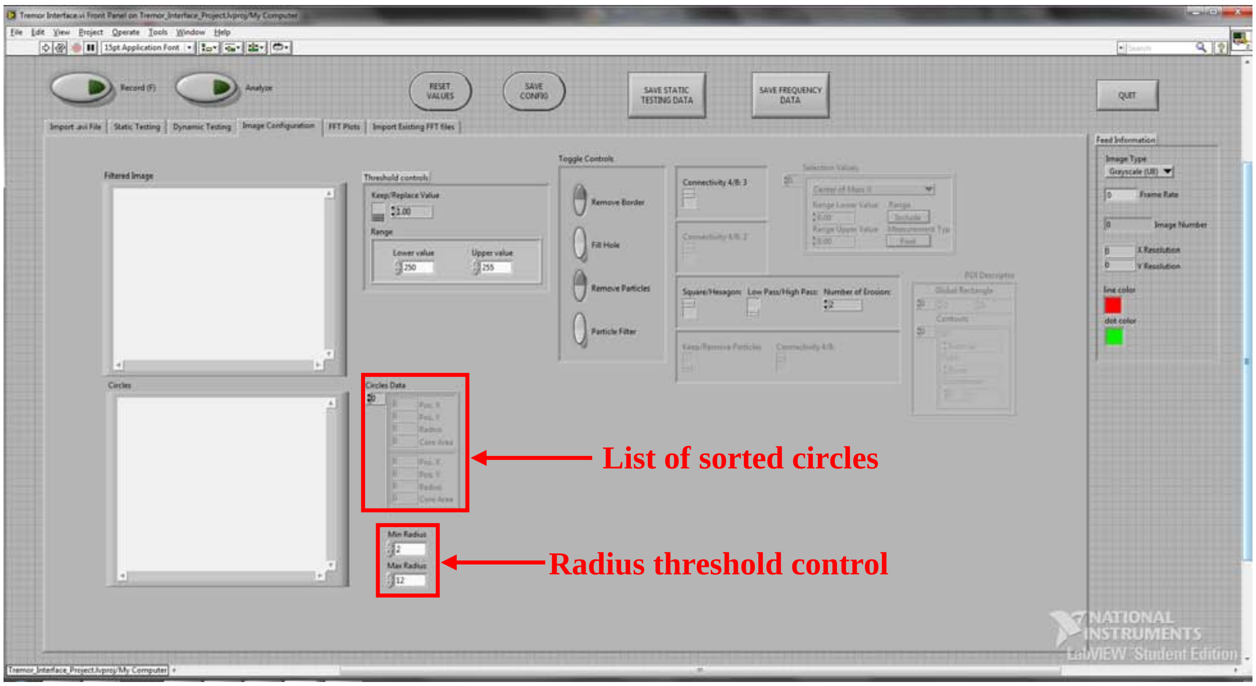
There is a camera feed window here to display how the image looks after processing. The user would probably be interested in the "Threshold controls" box. The options here are:

- Keep/replace value – determines whether to retain all pixels within the threshold bounds or to get rid of them and keep all pixels outside the threshold bounds
    - *(Default)* – keep
- Lower threshold [double] – sets value for the lower threshold
- Upper threshold [double] – sets value for the upper threshold

The camera feed will display what the threshold image looks like with the user selected values. This is important for running tests in different environments. The ambient lighting and the colors of the LEDs will force the user to play with threshold values until the correct lights are detected by the program.

IV.5. Finding Circles

At this stage, the logical high values from the threshold image are broken up into circles. The program will locate circles within a certain radius range and sort them in order to largest radius to smallest. In the same tab as the image processing controls (“Image Configuration” tab or “Video controls” sub-tab in “Import .avi File” tab), controls can be found to change discrimination for which radii to include and which to exclude in the radius range:



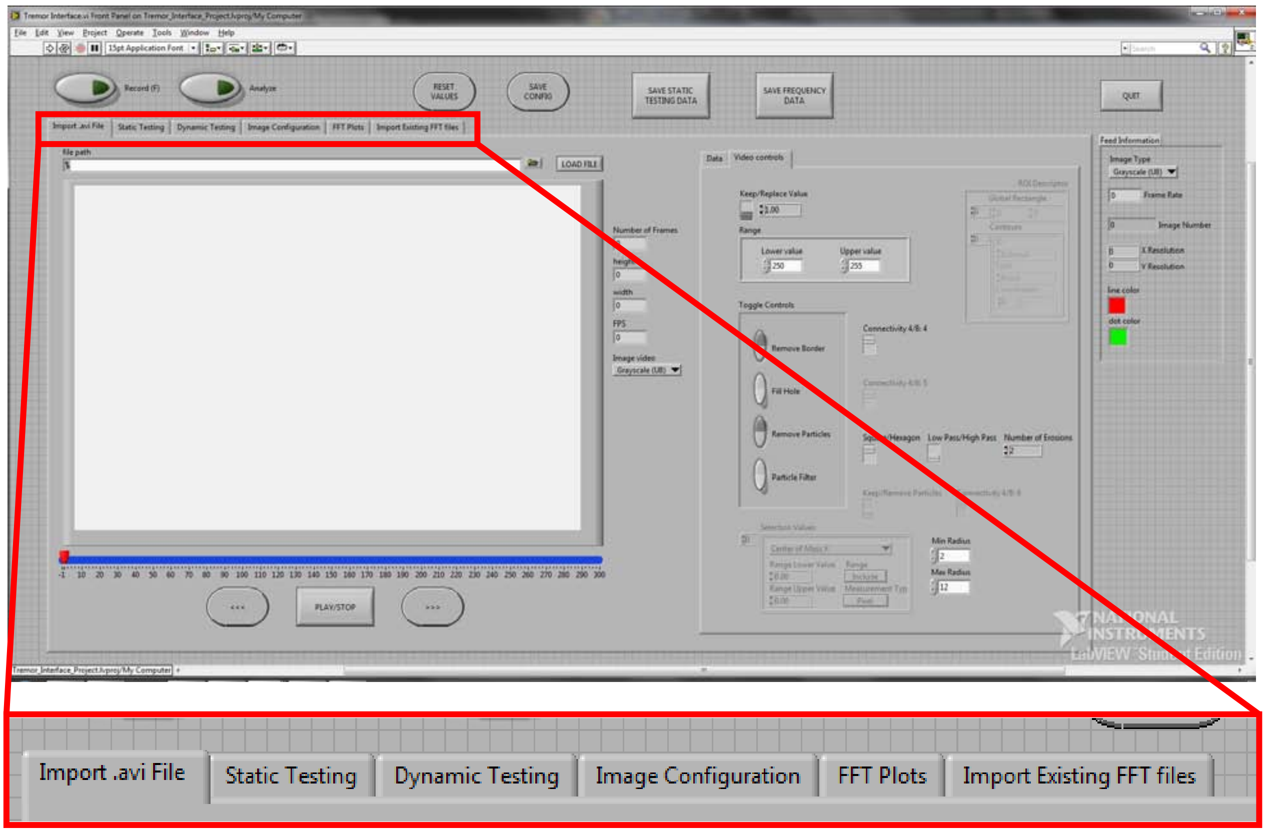
The screen above is for the “Image Configuration” tab. The controls look the exact same for the ones in the “Video controls” sub-tab.

The options here are:

- Radius threshold control – determines the range of radii from which to detect circles
  - Min radius [single] – determines the lower bound for circle detection
  - Max radius [single] – determines the upper bound for circle detection
- List of sorted circles [cluster] – sorts all the circles detected in the image by order of largest radius to smallest

V. Tabs

The front panel displays six tabs that the user can switch into. Each tab indicates a specific functionality for the program. Clicking on a tab changes the controls in the tab area to reflect new functionality. The tabs, found in the red box are as follows:



The description for these tabs can be found briefly outlined below and expanded upon in later sections of this document:

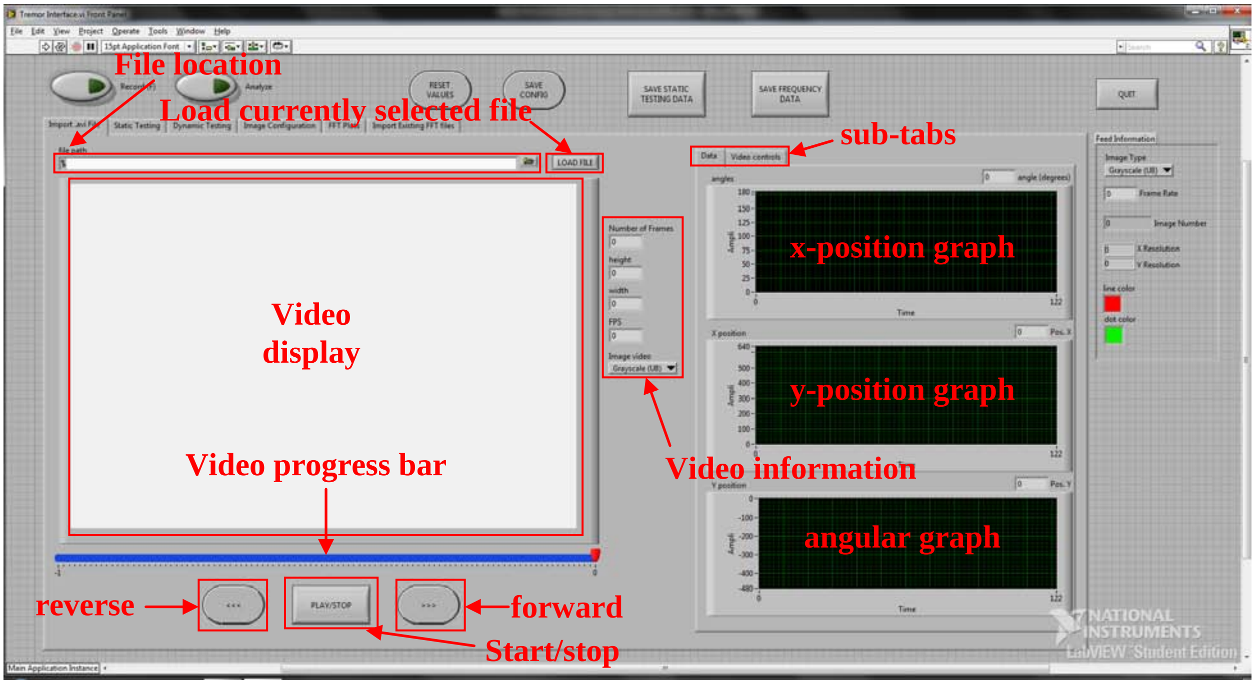
- **Import .avi File** – allows user to import .avi files and create x, y, and angular plots from an LED strap source in the video
- **Static Testing** – creates x, y, and angular plots from an LED strap source in a live video feed
- **Dynamic Testing** – finds the time the on-screen indicator generated from the LED strap source spends within specific concentric circles
- **Image Configuration** – Displays options on how to manipulate how the program sees the options to track the LED strap source
- **FFT Plots** – generates frequency plots of x, y, and angular data
    - Clicking on the ‘Analyze’ button while on the ‘Import .avi File’ tab generates frequency plots from the imported video’s x, y, and angular plots
    - Clicking on the ‘Analyze’ button while on the ‘Static Testing’ tab generates frequency plots from a live video feed’s x, y, and angular plots

- **Import Existing FFT files -** Allows the user to analyze previously saved .csv FFT files with options for discriminating peaks based on threshold and comparing peaks between different .csv files

This section divides up descriptions of the tabs and their usage under different subsections. For each tab, the first part will describe what the Front Panel controls are for. The second part will describe how to use the controls in the tab to extract information.

V.1. Tabs – Import .avi Files – Controls

The first tab, "Import .avi Files," should bring up the following screen:



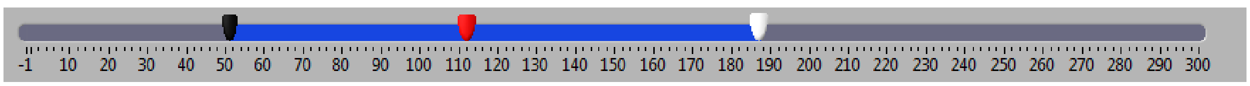
A description for each feature is as follows:

- **File path** – displays where in the system the .avi file is – blank if no file selected
- **Load file** – loads the .avi file that is currently in the file path
- **Video display** – window where the video will be played
- **Video progress bar** – shows the length of the video with three cursor controls, one to indicate the beginning frame to play back, one to indicate the current frame, and one to indicate the ending frame to play back
    - **Black cursor control** – drag this to appropriate place on progress bar in order to designate where to begin video playback
    - **Red cursor control** – indicates location of current frame – can be dragged to display a different frame
    - **White cursor control** – drag this to appropriate place on progress bar in order to designate where to end video playback
- **Reverse** – rewinds the video at twice the frame rate
- **Forward** – fast-forwards the video at twice the frame rate
- **Play/Stop** – plays and pauses the video
- **Number of frames** – displays the number of frames in the entire video
- **Height** – displays the number of pixels that make up the height of the video
- **Width** – displays the number of pixels that make up the width of the video
- **FPS** – displays the frame rate of the video
- **Sub-tabs** – within each sub-tab holds different information accessible to the user

- **"Data" sub-tab** – displays the x, y and angular plots for the LED strap position within the video segment bounded by the black and white progress cursors
- **"Video controls" sub-tab** - displays options on how to manipulate how the program sees the options to track the LED strap source for the imported .avi video feed
  - Has the exact same controls as the "Image configuration" main tab
  - Does not control the image analysis for the live camera

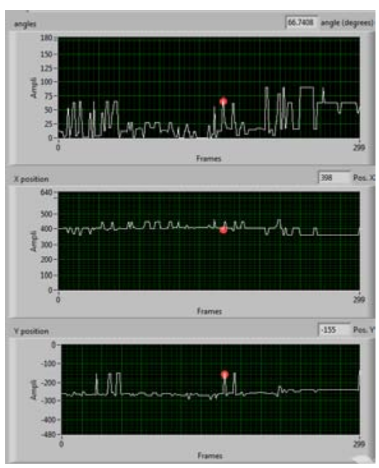
- **X-position graph** – displays the x-component of the LED strap source movement with respect to time for the video segment bounded by the black and white progress cursors
- **Y-position graph** – displays the y-component of the LED strap source movement with respect to time for the video segment bounded by the black and white progress cursors
- **Angular graph** – displays the angular-component of the LED strap source movement with respect to time for the video segment bounded by the black and white progress cursors

The video progress bar is shown below:



The progress bar counts by frames in the video, not by the total duration of the video. There are three cursors shown. A description of what each cursor does can be found in the previous page.

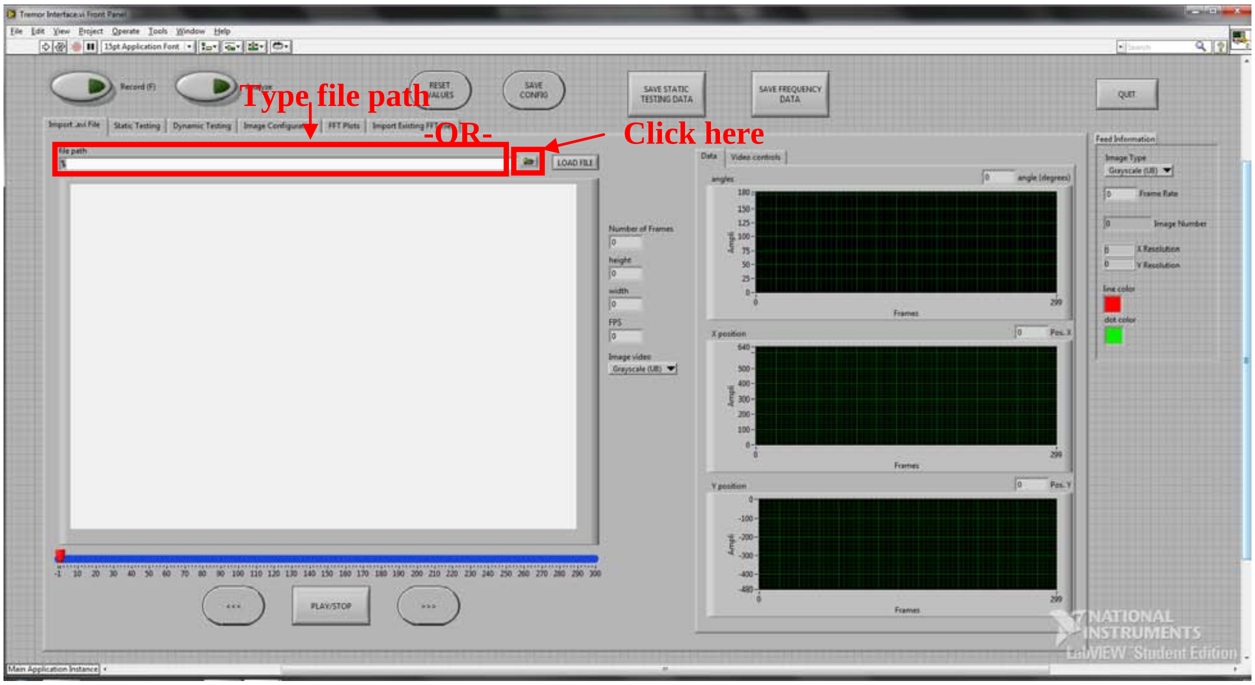
The following image displays the waveforms generated from a video:



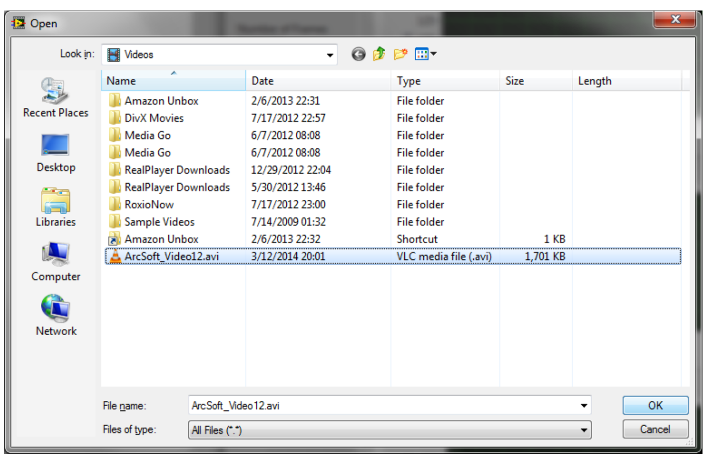
The red dot in the waveform indicates the current frame and will move as the red cursor in the progress bar moves. When the black and white cursors move in the progress bar, the beginning and end points for the x-axis will adjust accordingly to bound values between the black and white cursor frame values.

V.1. Tabs – Import .avi Files – Usage

Click the folder tab to the left of the “Load File” button in order to open up a file dialog. Alternatively, type in the file path in the field:

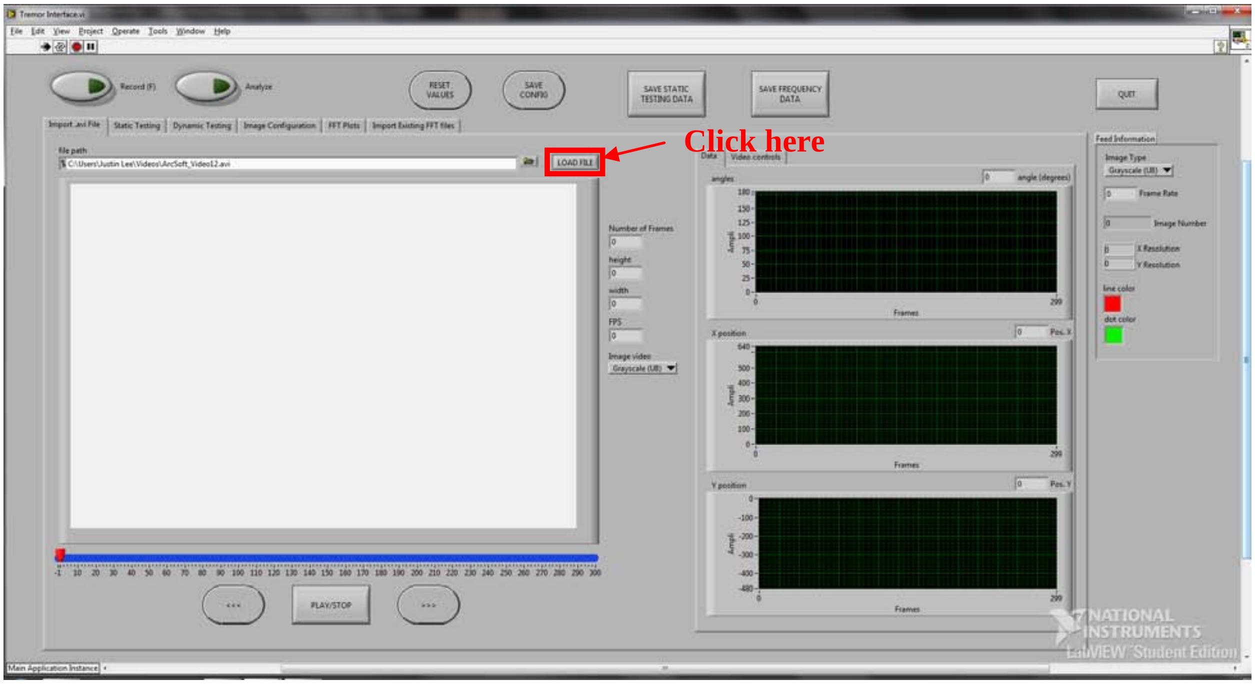


The file dialog will allow the user to select a file:



When the file is selected, press okay. The file path should be filled.

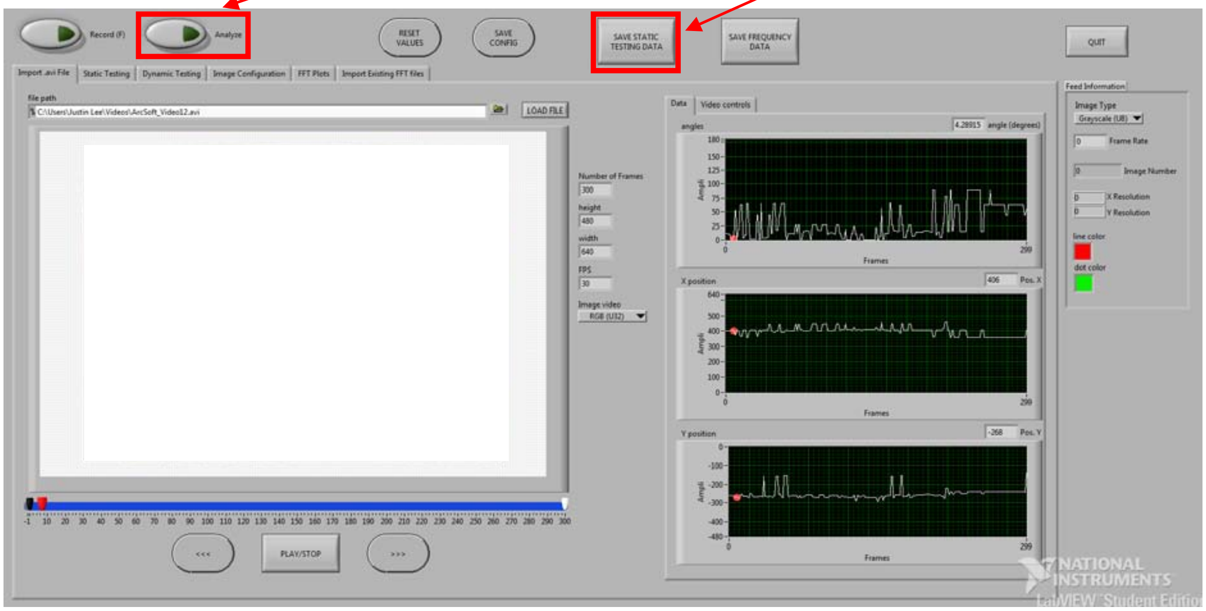
At this point, click on “load file:”



When “load file” is clicked, the program will automatically play every frame in order to locate the position of the LED strap. It will use the current settings in the “video controls” sub-tab in order to do this. The screen will lock until the all the frames are finished.

Once all frames are finished being analyzed, the video information fields should be filled with appropriate values and x, y, and angular plots should be generated. The black cursor will automatically jump to the beginning of the progress bar and the white cursor will automatically jump to the end:

Click here create FFT plots **Click here to save data**



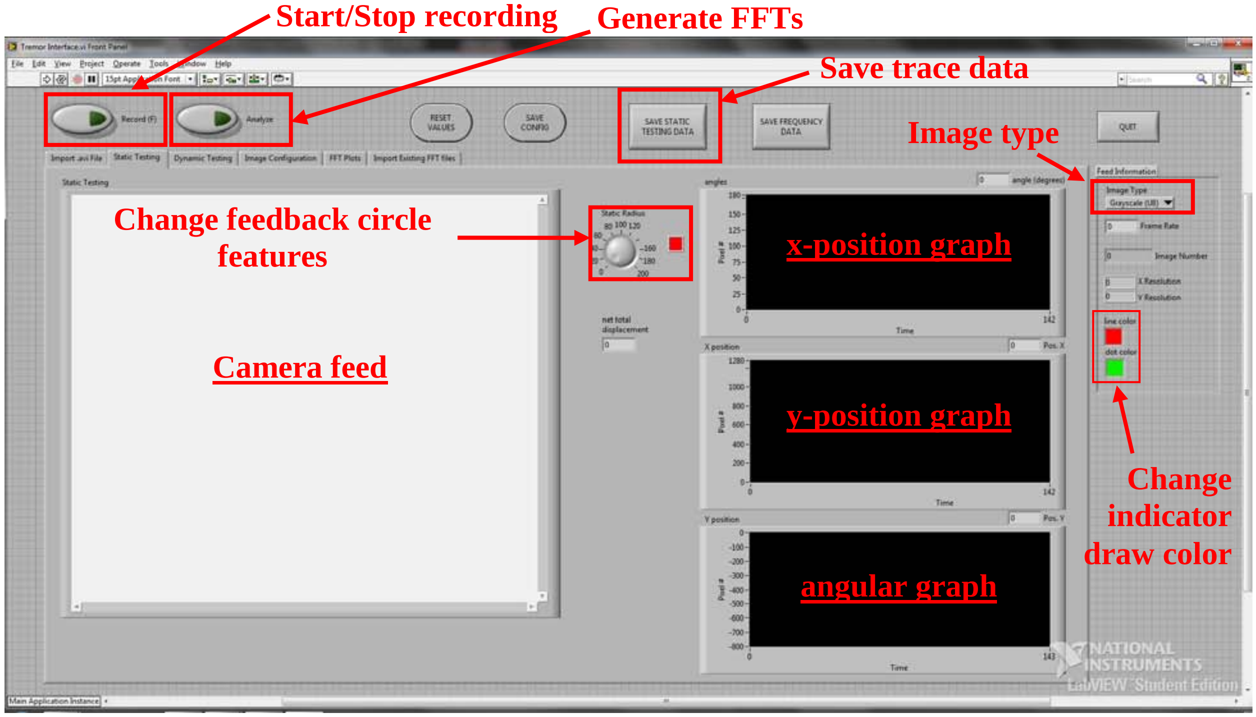
At this point, the user can press “Play/Stop” in order to start playing the video or drag the white and black cursors to appropriate places. The user can press the “forward” or “reverse” buttons in order to fast-forward or rewind, respectively.

Should the user change the options in the “Video controls” sub-tab, the video will have to be reloaded in order for the changes to take effect. If the user wants to save the x-positional, y-positional, and angular plots, press “Save Static Testing Data” program control on top. The x-positional, y-positional, and angular data that are bounded within the black and white cursor will be saved to a .csv file.

Click the “Analyze” program control in order to create FFT plots from the x-positional, y-positional, and angular data within the video region bounded by the black and white cursor. The main tab should automatically switch to “FFT Plots,” where the corresponding plot information is displayed. Click the “Save Frequency Data” button in order to save the FFT Plots to a .csv file.

V.2. Tabs – Static Testing Tab - Controls

The "Static Testing" main tab allows the user to collect positional and angular data from a live video feed. Refer to Section VI.2 – Camera Configuration in order to set up or change the camera to use. User interface options for the "Static Testing" tab are shown below:



Explanations for principle features on this tab are outlined below in alphabetical order:

- **Change indicator draw color** – choose colors for tracking indicator on the camera feed
  - **Line color** – change color of line that connects the two LEDs
  - **Dot color** – change color of dot that shows the center of the line that connects the two LEDs
- **Image type** – choose the data type which each frame can be processed as
  - Options include:
    - Grayscale – U8, U16, I16, SGL, CSG
    - RGB – U32, U64
    - HSL – U32
- **Save trace data** – Opens a dialog screen to output the data in the x-position, y-position, and angles produced to an .csv file
- **Start/Stop recording** – starts/stops the camera from recording footage
- **Change feedback circle features** – options to change the radius and color of the filled circle used in visual feedback
  - **Knob** – changes the radius of the visual feedback circle
  - **Color box** – changes the color of the visual feedback circle
- **X-position graph** – displays the x-component of the LED strap source movement with respect to time for the video segment bounded by the black and white progress cursors

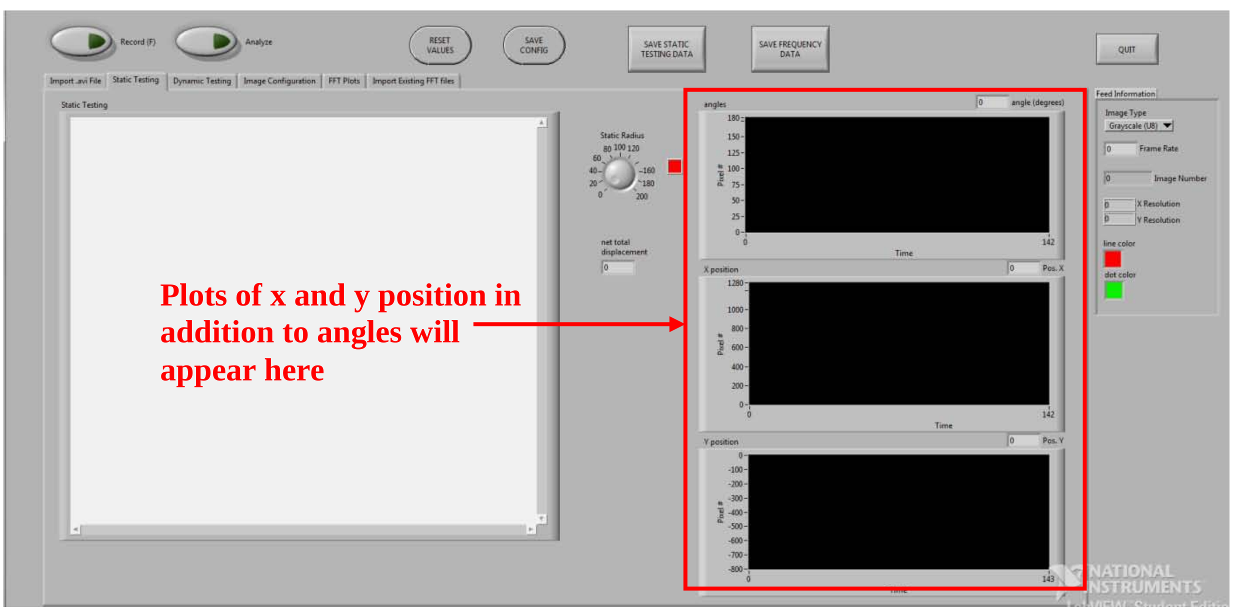
- **Y-position graph –** displays the y-component of the LED strap source movement with respect to time for the video segment bounded by the black and white progress cursors
- **Angular graph –** displays the angular-component of the LED strap source movement with respect to time for the video segment bounded by the black and white progress cursors
- **Analyze –** Generates FFT plots from the x-position, y-position, and angular graphs
    - Clicking this button takes the user automatically to the “FFT Plots” tab
- **Save static testing data –** saves the currently gathered -position, y-position, and angular data into an .csv file

V.2. Tabs – Static Testing Tab - Usage

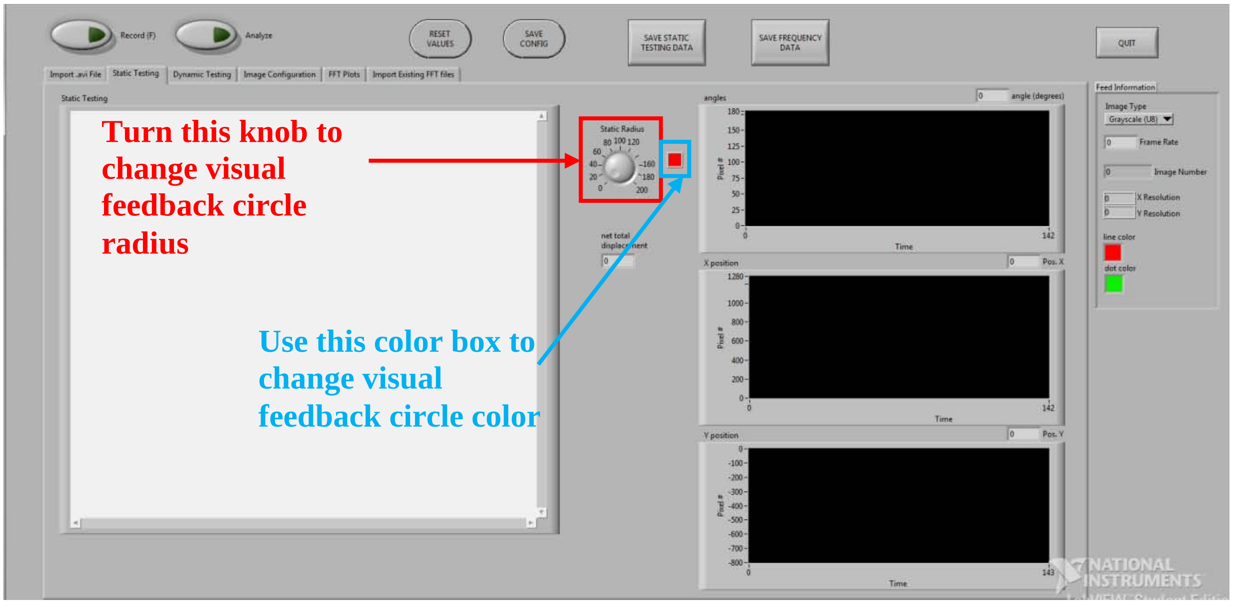
This subsection assumes that the user has already followed the instructions in Sections IV.2 and IV.3.

Once the program is running, the user can choose to start recording at any time. To record, press the “Record” program control on the top left corner of the screen:

It may take a few seconds to initialize, but the data should be beginning to collect on the trace plots. The traces will appear in the windows inside the red box below:



The visual feedback circle is there to help the test subject guide the LED strap source to the center of the image screen. The radius of the visual feedback can be changed with the indicated below:



Similarly, the control for changing the circle color is shown above.

Under certain lighting situations, the software will detect other light sources apart from the LED strap source. The program can be adjusted to change the parameters that it looks for when detecting light sources using controls under the "Image Configuration" main tab. The best strategy for changing these parameters is to keep the video running while the user adjusts. Once the user finds acceptable parameters, press the "Save Config" button at the top. Press "Record" in order to stop the recording. Afterwards, press "Reset Values" and initiate the recording process again. This ensures that the data acquired under the previous parameters are deleted. Otherwise, they will be factored into the FFT analysis and will give faulty results.

While collecting data, the user is allowed to cycle between this tab and the "Dynamic Testing" tab. When the user clicks on the "Dynamic Testing" tab, the graphs here will stop generating more time points. They will continue generating more time points once the user switches back to this tab, resulting in discontinuities in the data. It is therefore recommended to stop the recording and save the current data or output the data to FFT graphs before starting dynamic testing.

Collect data for an extended duration of time to get rid of noise. If the program starts to lag, end the collection. When collecting is finished, hit the "Record" button again. Then, hit the "Analyze" button shown below:

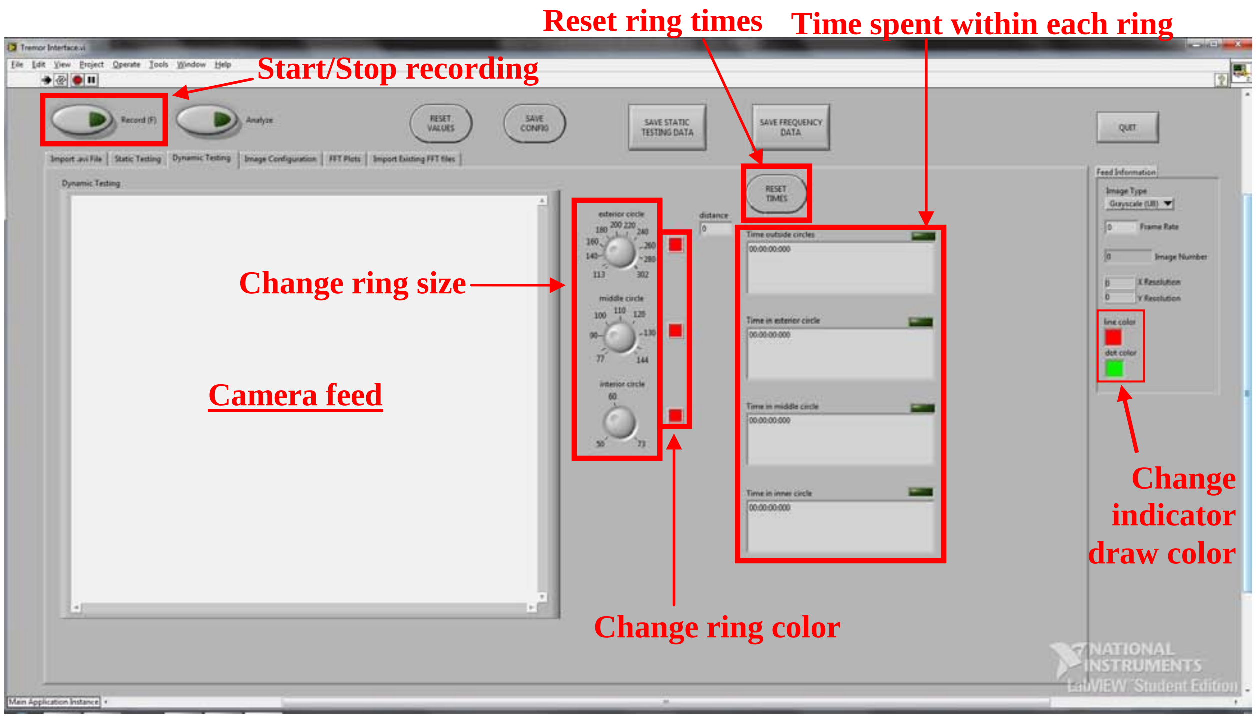
Click here when video is stopped

That will automatically bring the user to the "FFT Plots" tab:

If the user wishes to save the data, click the "Save Frequency Data" button on the top. If the user wishes to save the waveform graphs, return to the "Static Testing" tab. Then, click on the "Save Static Testing Data" button.

V.3. Tabs – Dynamic Testing - Controls

The “Dynamic Testing” main tab allows the user to track the amount of time the subject brings the LED strap source into certain sections of the screen. Refer to Section VI.2 – Camera Configuration in order to set up or change the camera to use. User interface options for the “Dynamic Testing” tab are shown below:



Descriptions of the features are as follows:

- **Start/Stop recording** – starts/stops the camera from recording footage
- **Change ring size** – changes the radius of the ring belonging to the adjusting knob
    - Ring radii are bounded by values of the adjacent ring and available values will change dynamically once the adjacent rings are made smaller or bigger
- **Change ring color** – changes the color of the ring belonging to the adjacent knob
- **Time spent within each ring** – indicates the time spent within the region bounded by adjacent rings
- **Reset times** – sets all the time indicators back to 00:00:00
- **Change indicator draw color** – choose colors for tracking indicator on the camera feed
    - **Line color** – change color of line that connects the two LEDs
    - **Dot color** – change color of dot that shows the center of the line that connects the two LEDs

V.3. Tabs – Dynamic Testing – Usage

This subsection assumes that the user has already followed the instructions in Sections IV.2 and IV.3.

Once the program is running, the user can choose to start recording at any time. To record, press the "Record" program control on the top left corner of the screen:

Alternatively, if the user has already started recording while in the "Static Testing" main tab, the "Dynamic Testing" tab can be clicked.

The camera feed will intialize and start recording. When the on-screen indicator for the LED strap source enters one of the available regions, the light next to the corresponding stopwatch box will go green. The stopwatch will then start. Once the indicator moves out of the corresponding region, the stopwatch will stop.

The user can adjust the knobs and color boxes to change features about the bounding circles indicated on screen. Should the user want to reset the stopwatch values, simply hit "Reset Times."

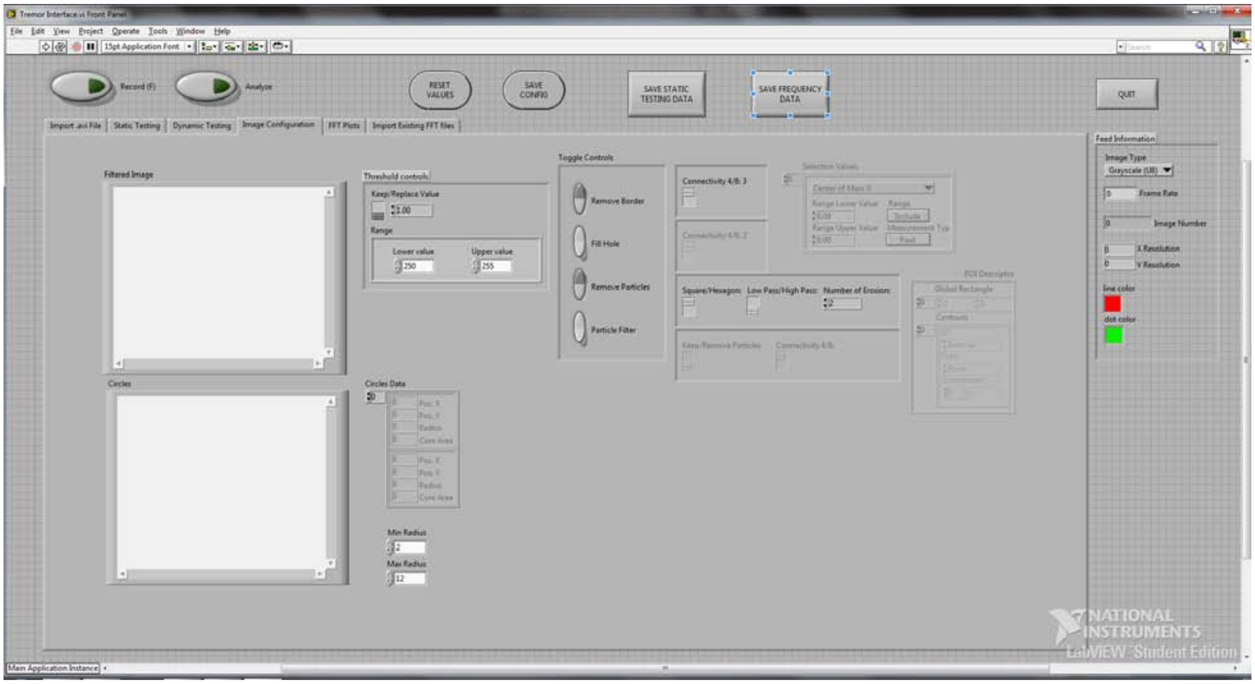
Under certain lighting situations, the software will detect other light sources apart from the LED strap source. The program can be adjusted to change the parameters that it looks for when detecting light sources using controls under the "Image Configuration" main tab. The best strategy for changing these parameters is to keep the video running while the user adjusts. Once the user finds acceptable parameters, press the "Save Config" button at the top. Press "Record" in order to stop the recording. Afterwards, press "Reset Values" and initiate the recording process again. This ensures that the data acquired under the previous parameters are deleted. Otherwise, they will be factored into the FFT analysis and will give faulty results.

While collecting data, the user is allowed to cycle between this tab and the “Static Testing” tab. When the user clicks on the “Static Testing” tab, the stopwatches will be paused regardless of which region the on-screen indicator is in. Once the user switches back to this tab, the stopwatches will activate accordingly. However, they will not record the times the subject spent in various regions while the “Static Testing” tab was active. Should the user want to continuously record time spent in each region, have a dedicated testing session to this. Once the user is finished recording, hit “Record” again to stop the capture.

It should also be noted that while the user is on this tab, no time points are being generated for the graphs in the “Static Testing” tab. Refer to Section V.2. Tabs – Static Testing – Usage for more information.

V.4. Tabs – Image Configuration

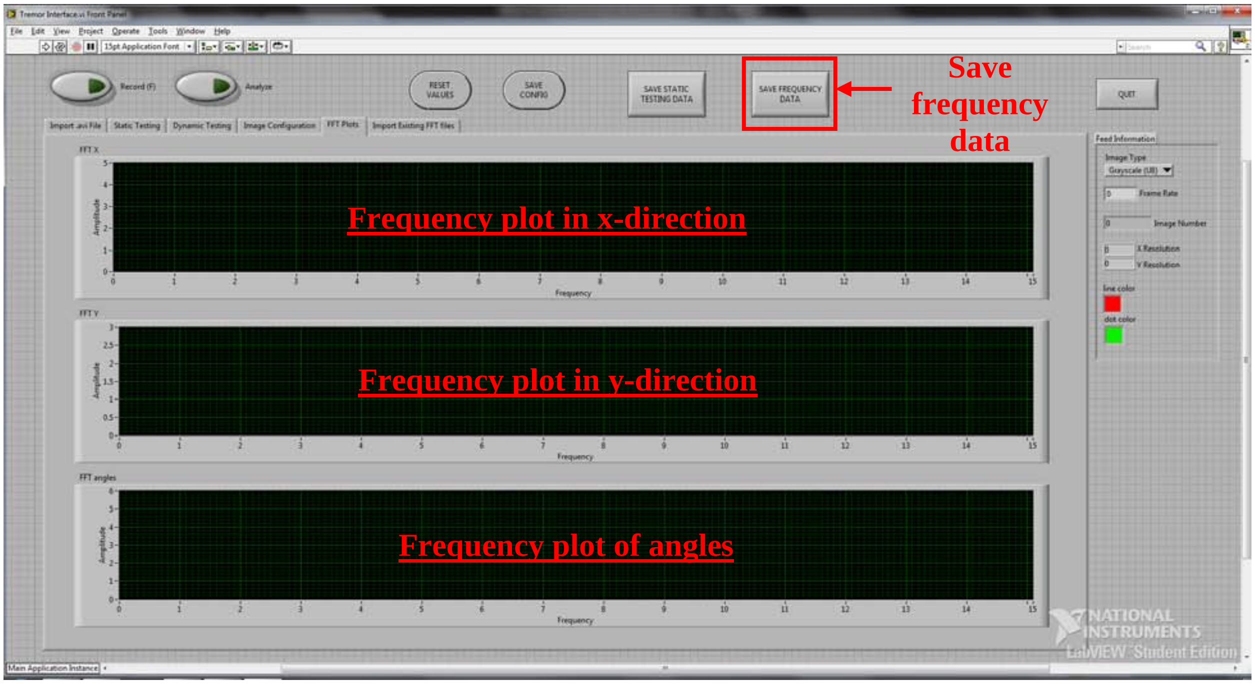
Clicking on the "Image Configuration" main tab brings up this screen:



These are all controls to change how the program analyzes each frame in a video feed to look for light sources. Refer to Section IV.4 – Image Configuration for more information.

V.5. Tabs – FFT Plots tab

This tab displays the FFT plots after the user hits "Analyze" in the program controls:

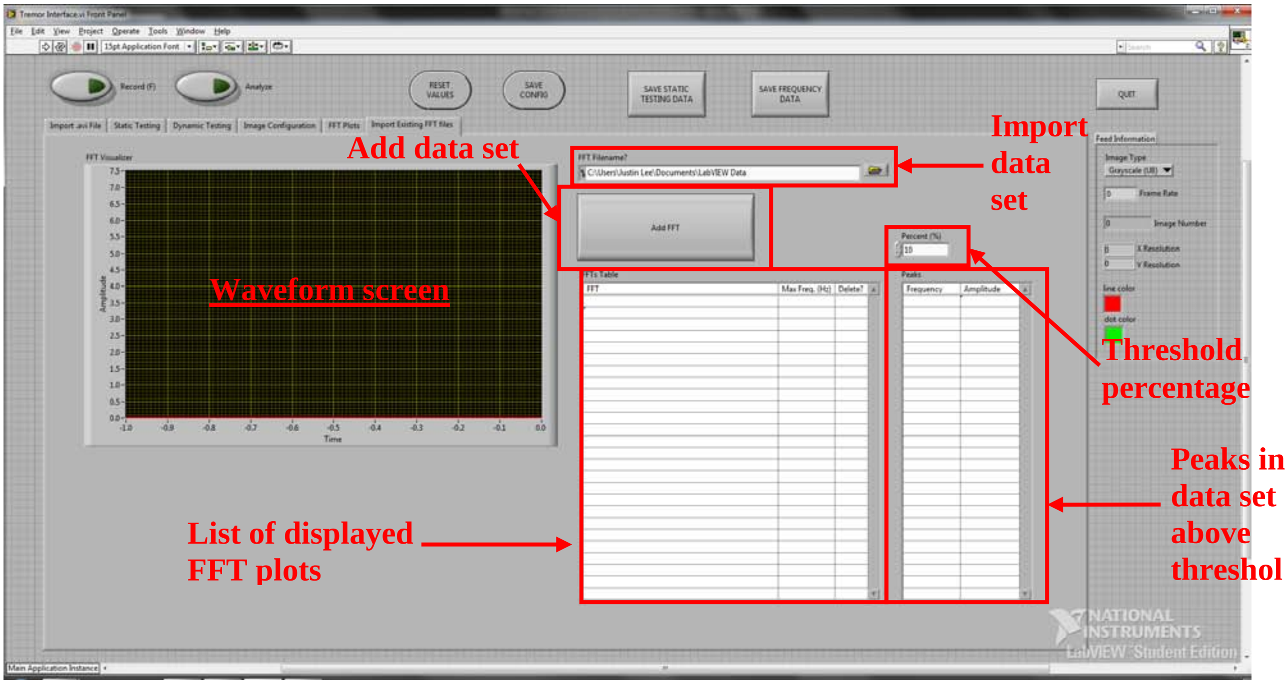


The only option here is:

- **Save frequency data** - Opens a dialog screen to output the x, y, and angular FFT plots into an .csv file

V.6. Tabs – Import Existing FFT files tab - Controls

Clicking on the “Waveform visualizer screen.vi” will bring up a window like this:



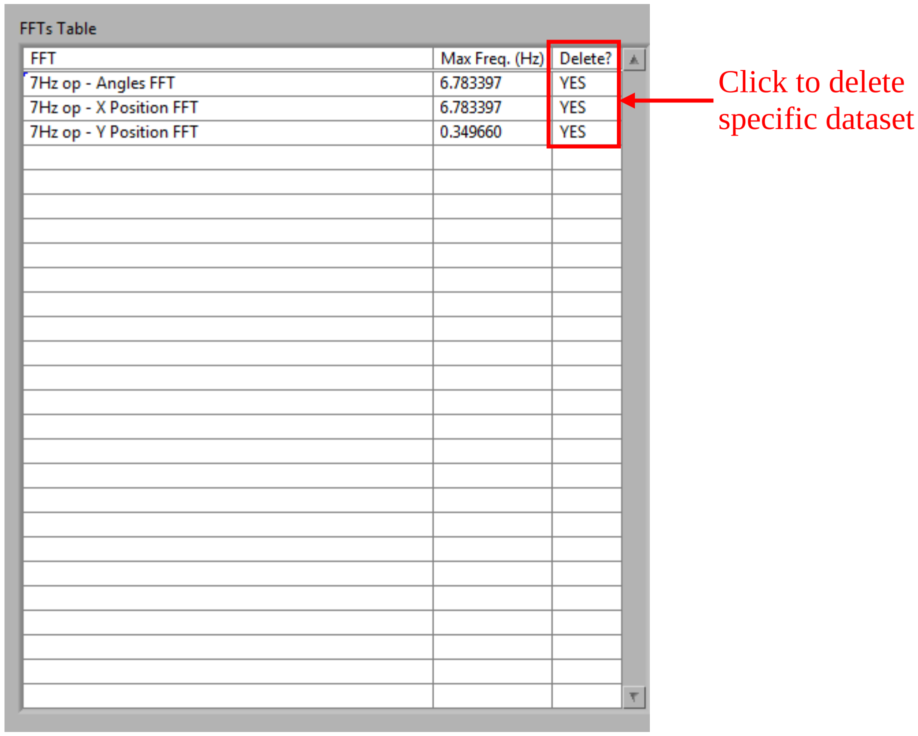
Explanations for user interface options are outlined below in alphabetical order:

- **Add data set** – opens up a dialog window allowing the user to select an .csv file to import
- **Import data set** – imports the dataset from the selected .csv file
  - Lists the FFT plots in the FFT table
  - Displays the plots on the waveform screen
- **Threshold percentage** – changes the threshold line to some percentage of the highest peak on the active FFT plot

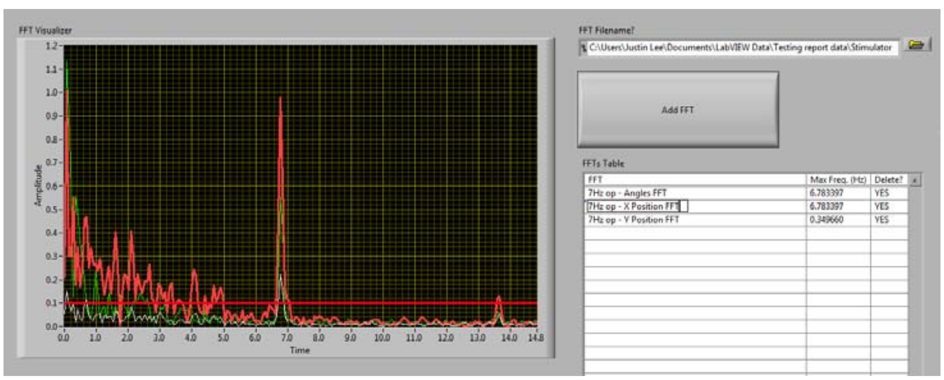
Explanations for the list of displayed FFT plots (FFT Table) and peaks in data set above threshold (Peaks) are described in the next section.

FFT Table:

The FFT table is shown below with data from a .csv file as an example:



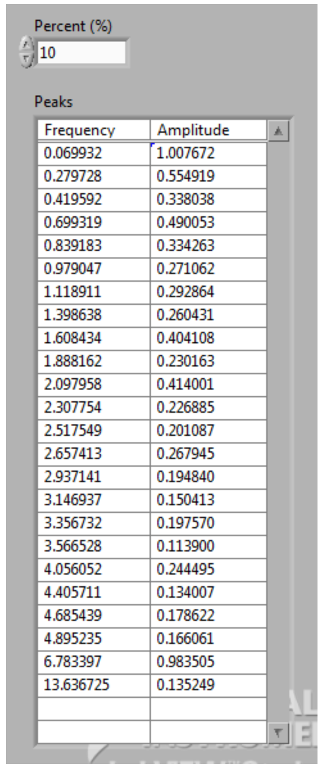
Loading a .csv file appends a list of datasets contained within the file to this table. In addition, the FFT plot corresponding to each dataset is displayed on the waveform screen. Clicking on the name of a dataset in the table highlights the corresponding plot on the waveform screen:



Next to the name of the dataset is the frequency value that corresponds to the highest amplitude for that set. Next to that is a field called “Delete?” Click on the “YES” to delete the corresponding dataset from the list, clearing it from the waveform screen.

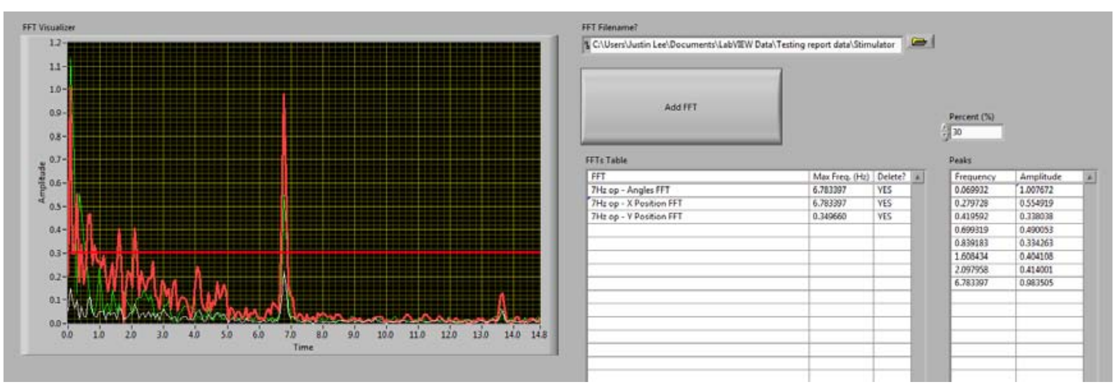
Peaks Table:

The Peaks table is shown below with data from a .csv file as an example:



Frequency	Amplitude
0.069932	1.007672
0.279728	0.554919
0.419592	0.338038
0.699319	0.490053
0.839183	0.334263
0.979047	0.271062
1.118911	0.292864
1.398638	0.260431
1.608434	0.404108
1.888162	0.230163
2.097958	0.414001
2.307754	0.226885
2.517549	0.201087
2.657413	0.267945
2.937141	0.194840
3.146937	0.150413
3.356732	0.197570
3.566528	0.113900
4.056052	0.244495
4.405711	0.134007
4.685439	0.178622
4.895235	0.166061
6.783397	0.983505
13.636725	0.135249

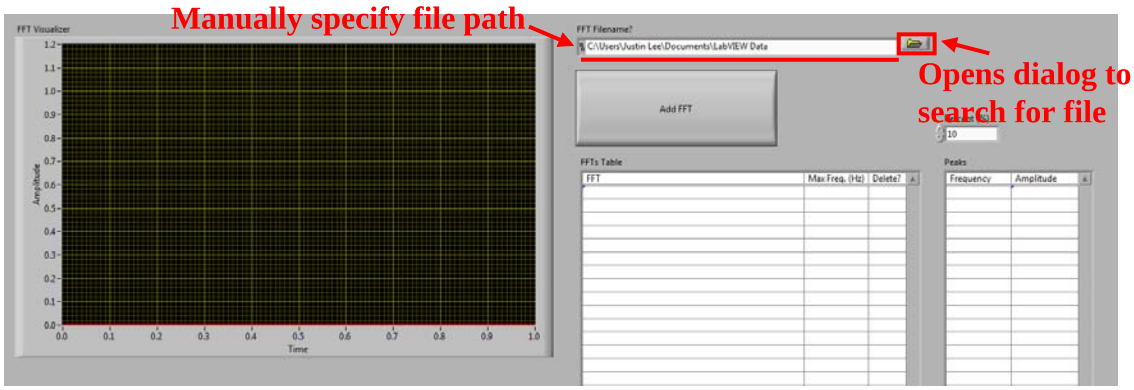
For a selected FFT plot, this table displays the frequency and amplitudes of all peaks above a specified percentage of the tallest peak. By adjusting the percentage level, the list should change to match the number of peaks above the new level:



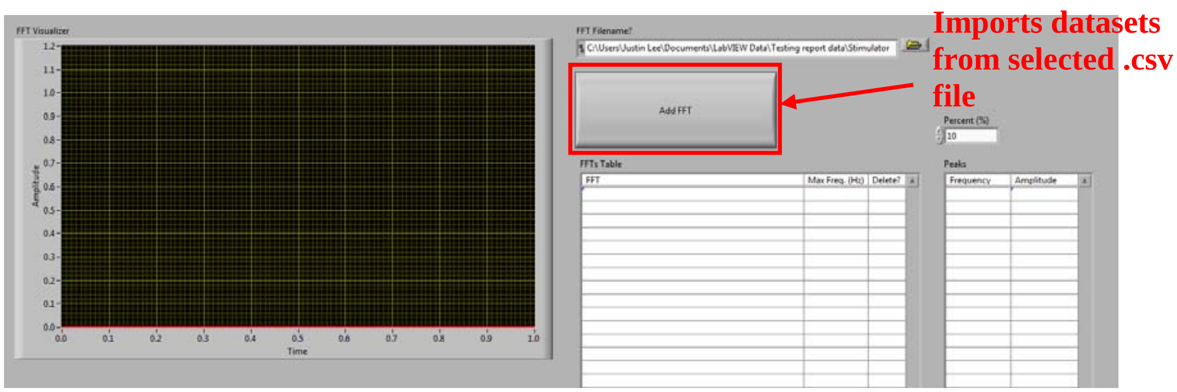
Notice that the percentage level is displayed visually on the waveform screen by a horizontal line that represents some percentage of the tallest peak in the currently selected FFT plot. Should the list not change immediately, re-click on the FFT plot name in the FFT table to refresh the screen. The list should change after that.

V.6. Tabs – Import Existing FFT files tab - Usage

Once the program is running, the user will need to import data. To choose a .csv file to import, click on the "open" button or manually type in the file path:

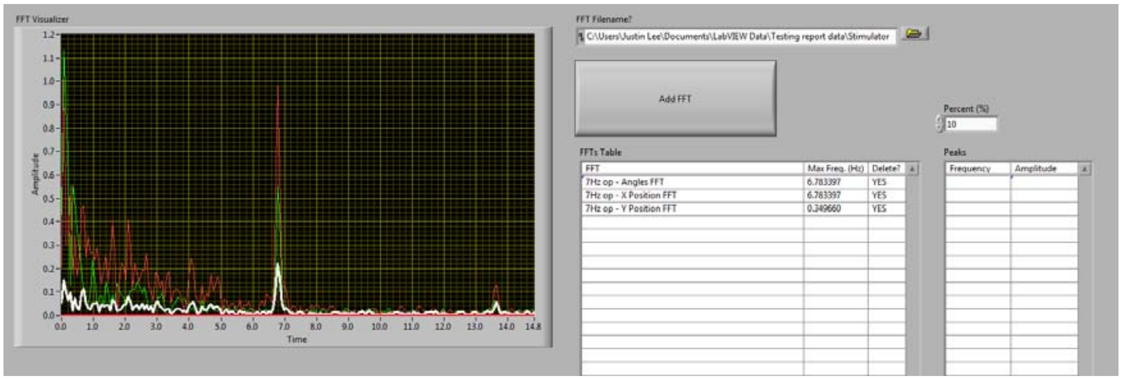


Once a file is found, click on the "Add FFT" button to import the datasets contained within the file:

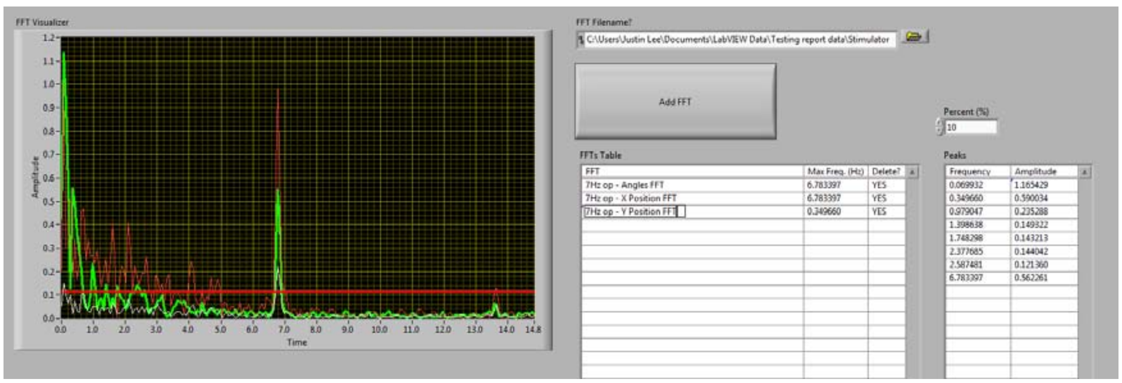


Should the user wish to add more files at any point, he can just repeat the process outlined in this page.

Importing a dataset will produce a screen that looks like this:

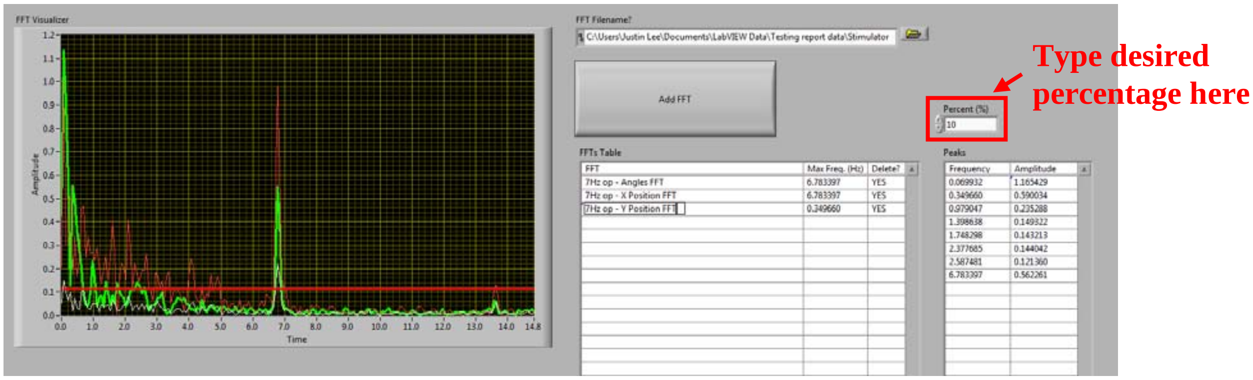


By clicking on one of the fields in the “FFT” column of the “FFTs Table,” the user can highlight a specific FFT plot:

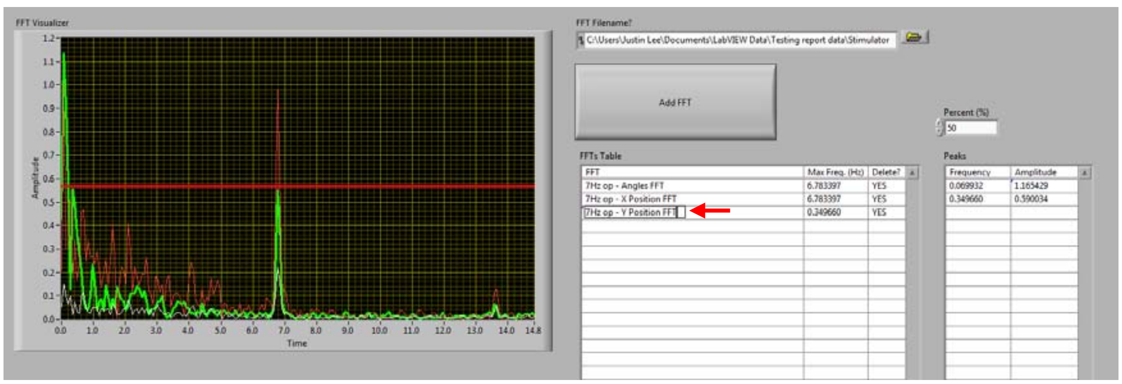


Notice that the green plot is highlighted. This indicates that it is the FFT plot corresponding to the name that the user clicked on. In addition, the horizontal line changed to correspond to the specified percentage of the highest peak on the selected plot. The frequencies of the peaks, and their amplitudes, listed in the “Peaks” table to the right represent peaks above the percentage.

By changing the percentage, the Peaks list will also change. To change the percentage, type in a new number between 0 and 100 into the "Percent (%)" field above the peaks table:

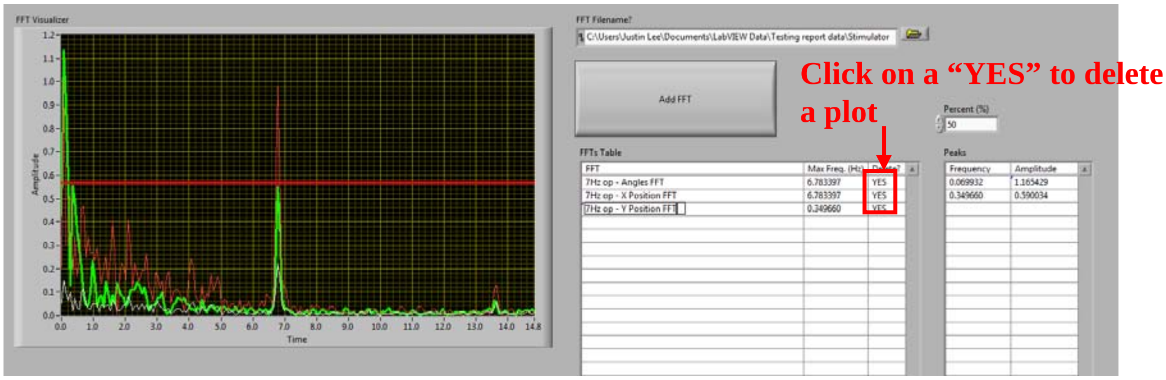


Once the percentage is changed, the user will have to re-click on the name of the FFT plot being examined in order to update the screen:

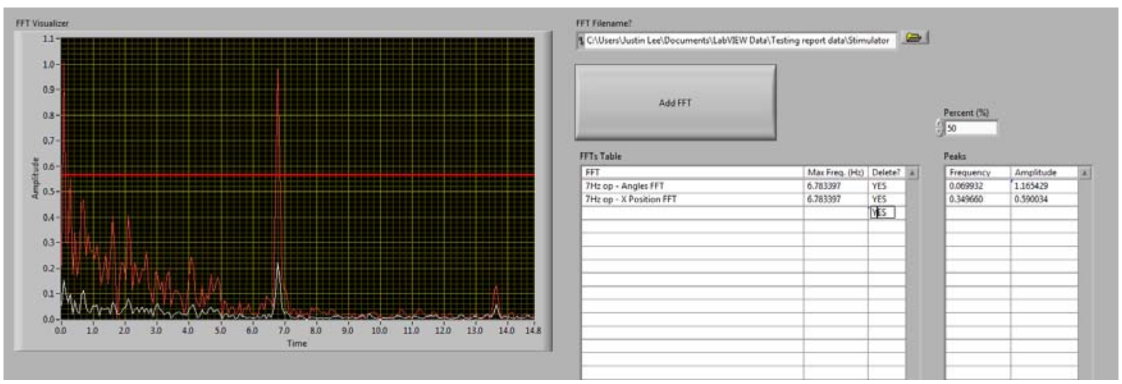


Notice that the number of entries in the "Peaks" table got smaller. This is consistent with the fact that a different percentage threshold was entered.

To delete a specific plot, simply click on the “YES” field on the far right of the “FFTs Table” that corresponds with the plot that the user wants to delete:



Deleting a plot will remove the plot from the waveform screen:



The green plot from the previous images has vanished, as has its entry in the “FFTs Table.” To examine another plot, click on that one’s name.

Appendix A: Introduction to Fourier analysis

While there are many reference materials on Fourier analysis, it is helpful to put a brief introduction into this documentation for future users who do not come from mathematics backgrounds. A minimal number of equations will be used in this section. Windowing will not be discussed here.

Fourier analysis stems from the idea that any function can be turned into a sum of sinusoids. That is, any function can be represented by:

$$f(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos(\omega n t + \theta_n) + b_n \sin(\omega n t + \theta_n)$$

ω is known as the angular frequency and calculated by $\omega = 2\pi f$. a_n and b_n are coefficients that change depending on the function being reproduced.

Now, the reader will note that the function will contain expressions that are integer multiples of some frequency f and that these multiples are expressed as nf. f is known as the **fundamental frequency** and any nf is known as a **harmonic frequency**. It is convention to call the component of the summation that uses a specific nf to be called the "nth harmonic."

This type of summation, known as **Fourier series**, applies solely to periodic functions. For non-periodic functions, the theory will be generalized into a **Fourier transform**.

Fourier series creates a summation for a periodic function based on discrete, integer increments of the fundamental frequency. The value of the amplitude at each frequency represents how much of that particular frequency is represented in the overall function. Generally, at very high frequency values, the corresponding amplitude is negligible. From this, important frequency components can be determined. Thus, it is important to solve for the amplitudes in order to determine which frequencies make a large contribution to the function in question. To solve for these coefficients $\{a_n, b_n\}$, use the following formulas[1]:

$$a_0 = \frac{1}{T}\int_T f(t)\, dt$$

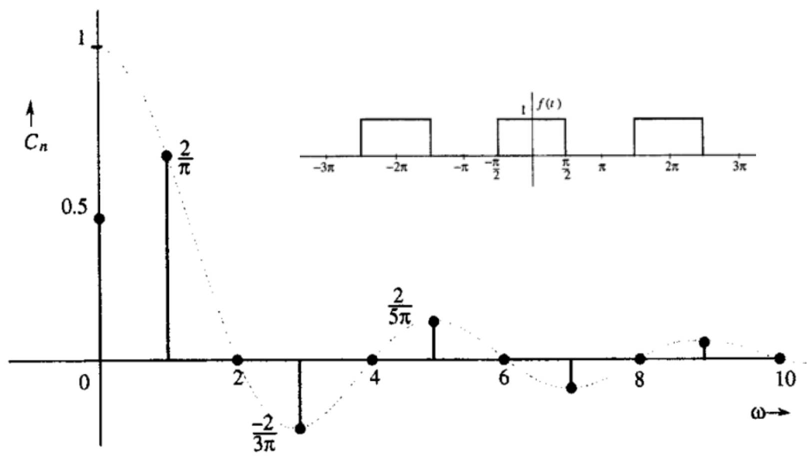
$$a_n = \frac{2}{T}\int_T f(t) \cos(n\omega t)\, dt$$

$$b_n = \frac{2}{T}\int_T f(t) \sin(n\omega t)\, dt$$

These produce different amplitudes for each discrete frequency. a_0 is simply a constant and is known as the average value a particular function. It represents by how much a function is shifted

[1] Equations will not be derived here, merely given

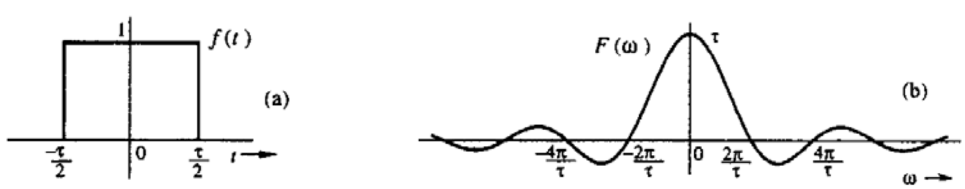
up or down the y-axis from $y = 0$. If amplitudes are solved for a range of frequencies, they can be plotted in a frequency vs. amplitude graph. This is known as a spectrum. Spectrums are useful because they allow us to see how frequency components develop or extinguish in a given function. The frequency spectrum for a square wave is shown below[2]:



Now, non-periodic signals require extending the theory from a discrete sense to a continuous one. The use of Fourier transforms, then, involves an integral instead of a summation:

$$F(\omega) = \int_{-\infty}^{\infty} f(t)\, e^{-j\omega t}\, dt$$

Instead of finding frequencies at discrete points on the spectrum, this will cause the frequency plot to "smear out" over the entire range of the x-axis. For example, the spectrum of a gate looks like this[3]:



Now, extending this to non-periodic discrete functions requires what is known as a **Discrete Fourier Transform (DFT)**. Much of digital data is non-periodic, making the DFT not only necessary, but essential to modern day life. A true explanation of the DFT and its process will not be offered here. However, it will be noted that DFTs are computationally expensive and incredibly slow. Alternative methods have been developed known as **Fast Fourier Transforms (FFTs)**. These are comparably faster than DFTs through heavy use of recursion. The Tremor software uses an FFT algorithm to compute the spectra. This gives the user desired frequency information and the contribution of each frequency to the change in light position.

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[2] Lathi, B.P., *Signal Processing & Linear Systems*. Oxford University Press, New York. 1998. p. 196.
[3] Lathi, B.P., *Signal Processing & Linear Systems*. Oxford University Press, New York. 1998. p. 247.

Appendix B: Format of the .csv files

Opening up a .csv file should give an Excel worksheet that looks like this:

A1 | fx | Fs

	A	B	C	D
1	Fs	Number of channels		
2	29.791	213		
3	Angles FF	X Position	Y Position FFT	
4	0.055	0.209	0.431	
5	0.152	1.007	1.134	
6	0.101	0.299	0.913	
7	0.064	0.299	0.581	
8	0.097	0.552	0.127	
9	0.019	0.178	0.556	
10	0.072	0.338	0.493	

The “Waveform visualizer screen.vi” automatically reads the data in the correct way in order to output appropriate plots. It is important not to change the order of any of the cells that appear in a .csv file.

Explanations of the fields are as follows:

Fs stands for sampling frequency (f_s). This is the average frame rate of the camera feed from the session.

Number of channels is the amount of data points for each coordinate (x, y, angular).

Angles FFT is the list of FFT sequence plots that corresponds to angular data. The number of points should equal the **number of channels**.

X Position FFT is the list of FFT sequence plots that corresponds to x-axis data. The number of points should equal the **number of channels**.

Y Position FFT is the list of FFT sequence plots that corresponds to y-axis data. The number of points should equal the **number of channels**.

As of right now, I am not sure how notes typed into blank fields will affect reading the .csv file. This will get updated once I know.