Nano-Route® 3D Manual

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Chapter 1: Introduction to Nano-Route®3D

Nano-Route®3D provides an interface for rapid Nano-Drive® command procedure development. The Nano-Route®3D LabVIEW application is a compilation of four uniquely suited Nano-Drive® utility VIs, each accessible as a separate “page” of a “tabbed” structure (resembling a file folder). Each page has been given a title which describes its function and which can be found on the tab for the page. The titles of the tabs from left to right are; *Device Information, Generate/Run Route, ISS Config., Build Graph Image*.

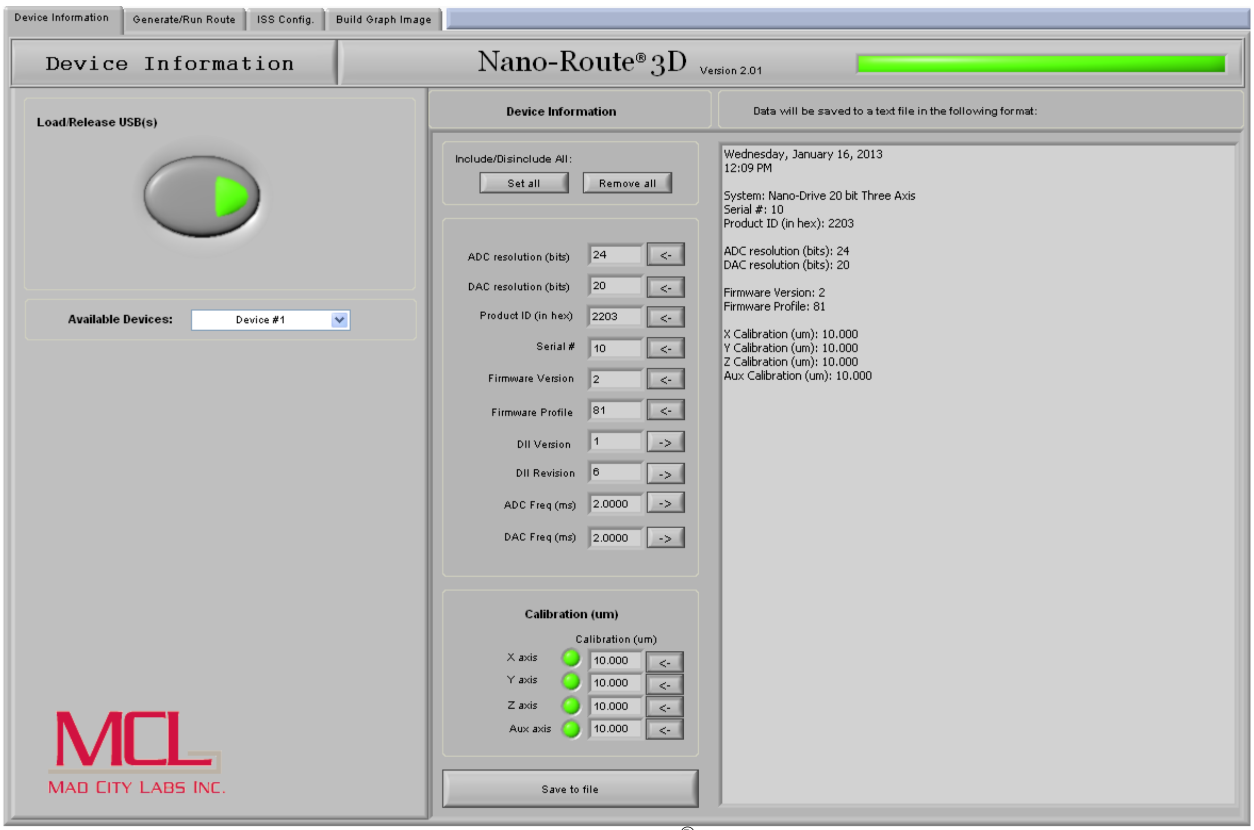


Figure 1.1 – Nano-Route®3D application.

Using Nano-Route®3D

A USB-enabled Nano-Drive® must first be loaded into the Nano-Route®3D application using the “Load Release USB(s)” button on the device information page; the application responds by identifying and displaying features of the Nano-Drive®. The user may now switch to the “Generate/Run Route” page of the application where motion command instructions (referred to as “Paths” within the application) are created according to input parameters, and displayed on a two dimensional graph. Multiple “Paths” can be easily linked together forming a larger sequence of motion commands (referred to as “Routes” within the application). Nano-Route®3D is compatible with USB enabled Nano-Drive® controllers that use Madlib.dll version 1, revision 6, or higher – Madlib.dll version and revision info can be found on the “Device Information” tab.

Data Acquisition with Nano-Route®3D

After a Route (a grouping of position commands) has been created, the user then “Runs” a specified axis through the Route, beginning an exchange of ADC/DAC values with the target Nano-Drive®. Nano-Route®3D retains in memory the ADC (sensor) and DAC (command) data retrieved from the Nano-Drive®, enabling the user to switch to the “Build Graph Image” page of the application to configure a graph of the retained data. From the “Build Graph Image” page the user has two options for exporting data; Nano-Route®3D will generate a text file containing the position, in microns, for each DAC/ADC datapoint or the Nano-Route®3D graph image can be printed directly using the *print-screen* button on your keyboard.

Section 1.1 - Key Nano-Route®3D Terminology

Path

Paths are the individual functions which make up a Route -- i.e. a single Path could bring the Nano-Drive® from an initial position of 2 microns to 50 microns over a period of 200 milliseconds. Following completion of the first Path, the Nano-Drive® would continue along any subsequent Paths, up until the last data-point of the last Path has been commanded.

Data-Point

Nano-Route®3D utilizes the concept of Paths and Routes for the convenience of the user; however, all motion commands made via the USB interface are made a single *datapoint* at a time – i.e. the Nano-Drive® never responds to more than one position command at a time. For example, a complex motion, such as a Sine wave, is attained using hundreds of datapoints. Paths consist of a number of data-points equal to the time span of the Path divided by the A/D (Analog-Digital) rate. In Nano-Route®3D, data-points are all evenly spaced according to the A/D rate.

Path Prototype

Nano-Route®3D allows the user to define complex Nano-Drive® motion commands within a simple, and intuitive, graphical interface. The user sets the parameters for the desired motion and Nano-Route®3D instantly generates a graphical representation of the motion command, referred to as the Path Prototype, or Path Preview. Once modifications to the Path Prototype have been completed, the user accepts the Path Prototype, adding it to the Route; a new Path Prototype then begins at the end of the accepted Path. The Path Prototype appears on the graph as a flashing, red line to distinguish it from accepted Paths (green).

Route

The Route is the entirety of accepted Paths. The Route consists of the data-points which will be issued to the Nano-Drive®, from left to right, at the designated A/D rate. The Path Prototype is not part of the Route. The accepted Route appears on the graph as a green line.

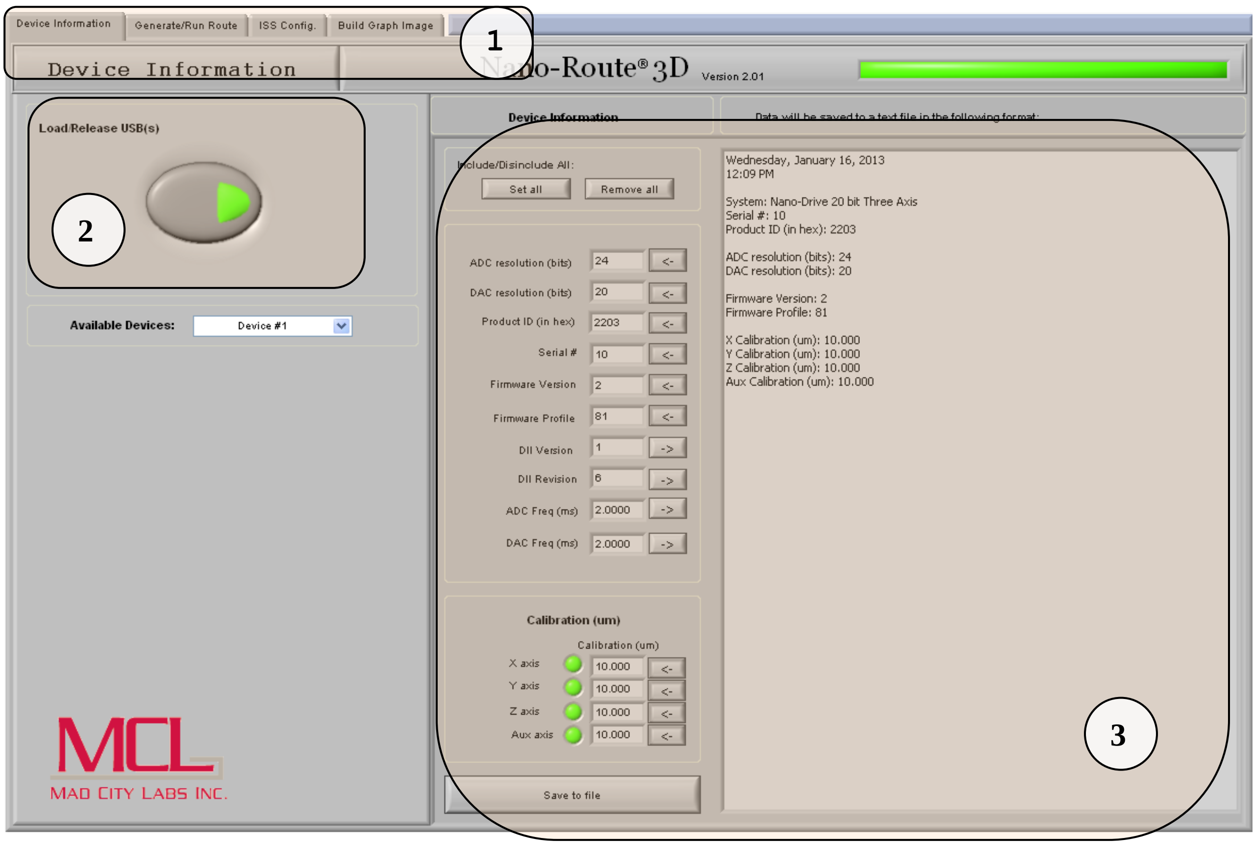
Chapter 2: Device Information

Interaction with the Nano-Route®3D application begins at the “Device Information” page. A USB-enabled Nano-Drive® must be loaded into the Nano-Route®3D application before proceeding to other tabs of the application. When a Nano-Drive® has been successfully loaded the application responds by identifying and displaying features of the Nano-Drive® within the device information window (highlighted as function “3” in the image below).

The Labeled Functions of the “Device Information” Page

1. These tabs provide access to the separate pages of this application.*
2. Load the installed Nano-Drive® for use within the Nano-Route®3D application.
3. Device information is displayed here.

* This function is available from all pages of the application



Chapter 3: Generate or Run a Route

The most important functions of the Nano-Route®3D application exist on this page. This is where Paths are created and Routes are commanded.

The Seven Labeled Functions of the "Generate/Run Route" Page

1. These tabs provide access to the separate pages of this application *
2. Save/load a state of the VI **
3. Device and Route configuration **
4. A graphical display for the generated Route **
5. Configure, add, delete, or cycle through paths **
6. Run the current Route, or all existing Routes simultaneously **
7. Configure and begin a Raster Scan **
8. Displays streaming position data **
9. Open the Gamepad control window **

* This function is available from all pages of the application
** This function is explained in further detail below

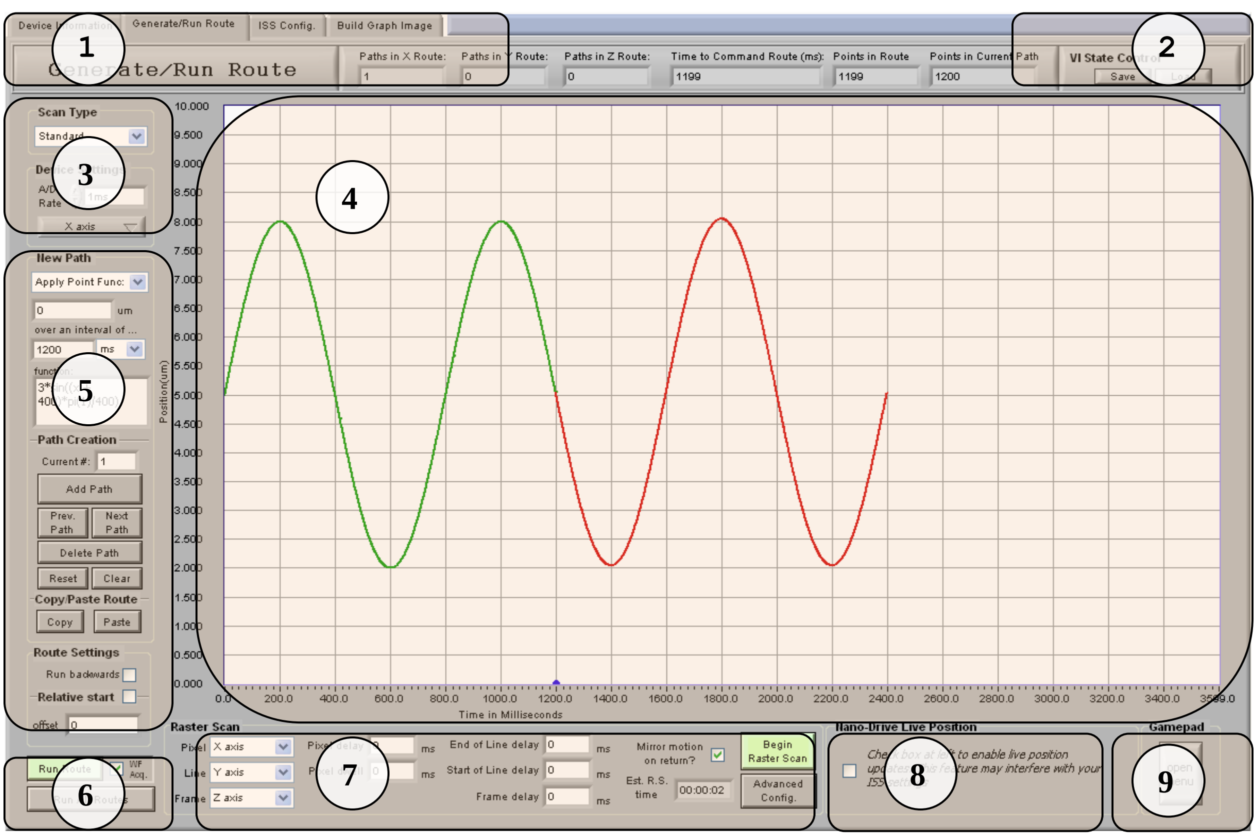


Figure 3.1- The Generate/Run Route page. Eight key areas are highlighted.

VI State Control
Use the save or load button at the top-right corner of this tab (Figure 3.1, area 2) to save or restore a "state of the Nano-Route®3D VI". Nano-Route®3D saves the Routes and some associated values to disk for later use.

Device and Route Configuration
The Path Prototype (flashing red Path) is governed by the parameters set within the *New Path* panel (Figure 3.1, area 3). This is also where you will set the axis to which the Path will belong, and the rate at which the datapoints will be commanded (A/D rate).

- ***Scan Type***
  Choose a scan type to clear the front panel of controls which don't pertain to your scan. The "standard" scan type shows/restores all controls and is selected by default.

- ***Device Settings***
  The Route for each axis of the Nano-Drive® must be programmed separately. Select which axis the Route will belong to using the control on this panel. The A/D (Analog-Digital) rate defines the rate data-points will be issued to the Nano-Drive® (faster settings may mean the loss of certain "Run" options.)

- ***Route Settings***
  Check the "Relative Start" checkbox within this panel and Nano-Route®3D will consider the 0 marker of the Graph's Y-axis to represent the current position of the Nano-Drive®. For example, a Nano-Drive® Z-axis is extended to 13um, and X-axis is extended to 8 um, a route built to ramp from 0um to 5um is copied and pasted to both axes. After checking the "Relative Route" checkbox, a raster scan is performed using both Z and X which ends with the Z-axis at 18um and the X-axis at 13um.

A Graphical Display for the Generated Route
A display of the generated route is shown in Figure 3.1 (area 4). The plots graphed within this window are the position-command points which the Nano-Drive® will follow. In Nano-Route®3D altogether these points are referred to as the Route. Y values of the Route represent the position, in microns, being commanded; X values represent the order of execution, which on the graph could be either the time (in milliseconds from the start), or the datapoint index within the Route, when the value will be commanded. This graph enables the user to visually inspect the generated command route.

- ***New Path***
  The Path Prototype is generated according to the parameters set within this panel. Define the type of movement with the pull-down menu. There are 4 options available in the pull-down menu: "Remain at", Ramp To", "Apply Point Func:" and "Apply Time Func:" The simplest path options, "Remain at" and "Ramp to", only require the user to define a displacement/position value to move to, and an amount of time/dpts the path should span. The "Apply Point Func:" and "Apply Time Func:" options require the user to mathematically define the motion within the "function:" text box. More detail on using the "Apply Point Func:" and "Apply Time Func:" Path definitions can be found in *Chapter 7 – Applying Functions*.

Configure, Add, Delete, or Cycle through Paths

The following options are available to the user from the *Path Creation* panel (see Figure 3.1, area 5). This panel allows you to combine paths to create routes, cycle through the Paths which make up the Route, insert or delete new Paths, or copy entire Routes to be pasted onto other axes at any time.

- ***Add Path***
  Left-clicking this button will accept the current Path Prototype (flashing red Path), adding it to the Route (green grouping of Paths). Upon pressing the Run button each datapoint along this Path will be individually commanded to the Nano-Drive® in left to right order.

- ***Previous Path / Next Path***
  Once a Path has been added to the Route using the Add Path button it can no longer be edited. However, any accepted Path can be deleted and replaced. To do this, the user must cycle backward using the "*Prev.*" button to highlight the Path. After deleting a Path, return to the end of the Route using the "*Next*" button. Also, using the "*Prev.*" and "*Next*" buttons new Paths can be inserted into the Route between accepted paths.

- ***Delete Path***
  Left-clicking this button will remove the currently highlighted Path from the Route. If a portion of the Route follows the deleted path, it is automatically brought backward to seamlessly connect the remaining Paths. Use the Previous Path/Next Path buttons to highlight the desired Path.

- ***Reset***
  Left-clicking this button removes all accepted Paths from the Route, effectively deleting the Route. Upon clicking, a pop-up window will request confirmation of this action.

- ***Clear***
  Left-clicking this button will clear the ADC (Sensor) data from the Graph. Left-clicking this button will not affect the Route or any Paths.

- ***Copy / Paste Route***
  A single Route can be copied then pasted at any time. After programming a Route, left-click the "Copy Route" button to store the Route in memory. Left-click the "Paste Route" button at any time to replace the plotted Route with the stored Route. This feature is especially useful for copying and pasting Routes from one axis to another.

Run the Current Route, or All Existing Routes Simultaneously
Use the *Run Route* or *Run all Routes* button at any time to begin commanding the Nano-Drive® through the Route (see Figure 3.1, area 6). Upon completion, a blue plot of ADC (Sensor) values appears on the "Generate/Run Route" graph, and Nano-Route®3D automatically switches to the Build Graph Image tab.

- ***Waveform Acquisition***
  There exists two ways to issue motion commands to a Nano-Drive®; single writes, and *Waveform Acquisition*. Checking the "WF acq." check-box will guarantee the datapoints of the Route are issued in the waveform acquisition mode. See the section on "choosing an Analog-to-Digital rate" for more on the advantages of Waveform Acquisition. Waveform Acquisition cannot be used when running all routes.

Configure and Begin a Raster Scan
Nano-Route®3D is capable of coordinating complex Raster Scans involving up to three axes. Generating raster scans is described in more detail in *Chapter 9 – Raster Scans*. This menu allows the user to choose how each axis will interact during the raster scan using the Pixel, Line, and Frame pull-down menus (see Figure 3.1, area 7). Begin the raster scan with the "Begin Raster Scan" button located to the right of the raster scan configuration options. Nano-Route®3D will begin counting down to the completion of the raster scan within the "Estimated R.S. Time (seconds)" indicator. Use the "Stop" button to prematurely end the raster scan.

- ***Pixel, Line, and Frame***
  Use these controls to designate the task of each axis involved in the raster scan, or to remove an axis from participation in the raster scan. An axis designated as the Line axis will increment one point in its route for every completed Route of the axis designated as the Pixel axis. An axis designated as the Frame axis will increment one point in its Route for each completed Route of the Line axis.

- ***Delay Options; Pixel, End of Line, Start of Line, Frame***
  Artificial delays can be added in millisecond increments at the following nodes of the Raster Scan; after each write (but before each read) on the Pixel axis *(Pixel)*, after a Pixel Route has finished *(End of Line)*, before a Pixel Route has begun *(Start of Line)*, after a Line Route has finished *(Frame)*.

- ***Mirror motion on return***
  With this option checked, the Pixel axis will alternate the end from which it begins the next line; i.e. a ramp from 0 microns to 10 microns becomes a triangle wave as during the proceeding line the Pixel axis will move from 10 to 0 microns, taking it back down the ramp.

- ***Advanced Configuration Options***

Use this button to set the Pixel axis to move via Waveform Acquisition and to access settings which describe the Waveform Acquisition. See the section on “choosing an Analog-to-Digital rate” for more information on Waveform Acquisition.

Displays Streaming Position Data (Nano-Drive® Live)
Check the box in this panel to gain access to streaming position updates. While otherwise idle, Nano-Route®3D constantly reads the position of all existing axes and displays the data here (Figure 3.1, area 8). In addition, each axis can be individually commanded from this area. This option is off by default because it will interfere with ISS enabled systems.

Open the Gamepad Control Window
Click this button to open a window which enables Gamepad control of a Nano-Drive®. While the Gamepad control window is open, all other processes of the Nano-Route®3D application are suspended, and Nano-Route®3D prevents interaction with its Front Panel. The Gamepad control window functions similarly to the “Gamepad Nanocontrol” vi supplied as a LabVIEW example with your Nano-Drive® software. Refer to the GamePad Nanocontrol Appnote for information regarding the use of this subvi.

Chapter 4: ISS Configuration

For USB enabled Nano-Drive® controllers with the ISS option, Nano-Route®3D provides a visual interface for configuring some, but not all, of the ISS options. The ISS option offers the user four clocks; pixel, line, frame and auxiliary; to assist scan synchronization with external hardware.

The Labeled Functions of the "ISS Configuration" Page

1. These tabs provide access to the separate pages of this application *
2. The main ISS configuration interface **
3. Confirm or reset the ISS configuration **
4. Configure ISS commands for the beginning and end of each scan **
5. Pulse any of the ISS clocks **

* This function is available from all pages of the application
** This function is explained below

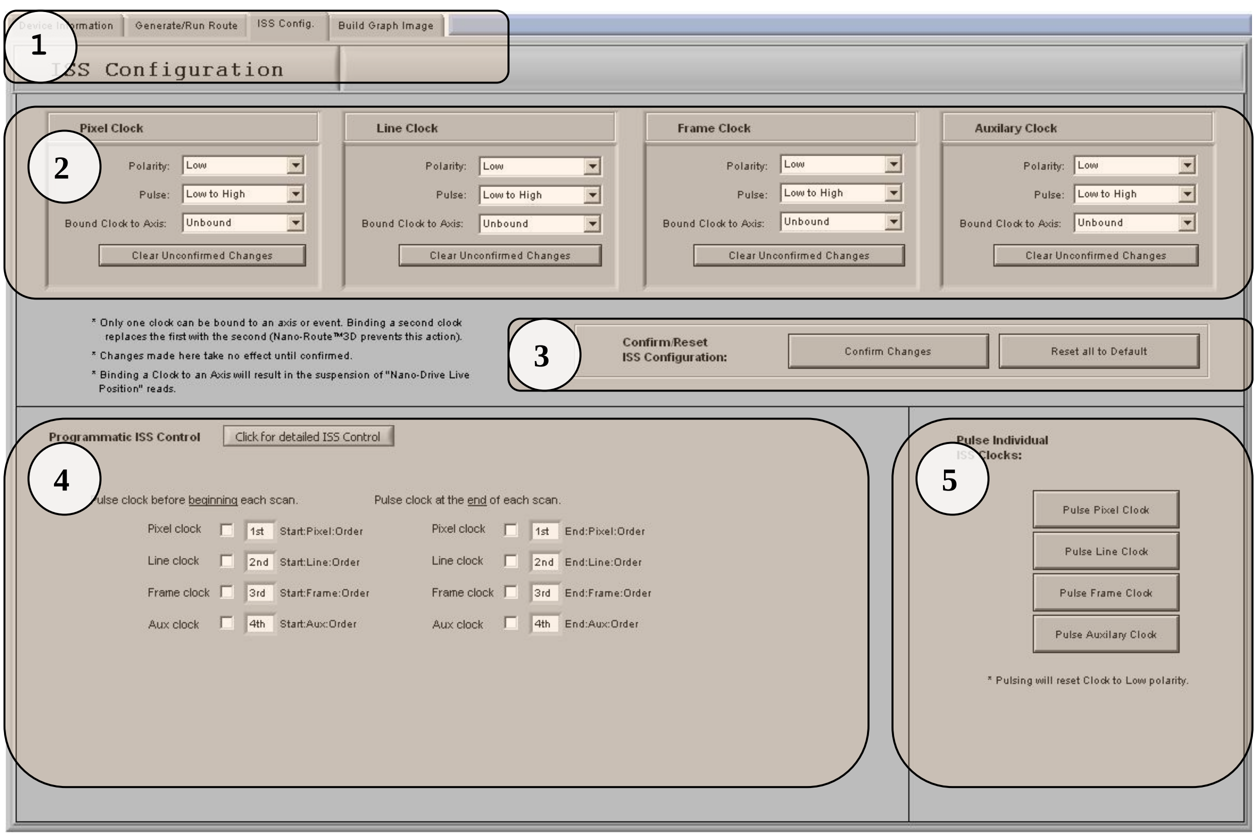


Figure 4.1 – The ISS configuration page with 5 key locations noted. Explanations of each location are discussed in this chapter.

The Main ISS Configuration Interface
Each clock can be configured using this panel (Figure 4.1, area 2). The user specified parameters are described below.

- ***Polarity***
  Set the idle state of the Clock (High or Low). This does not affect the Pulse (i.e. a Clock which is idle High will go low for the first half of a low-to-high pulse).

- ***Pulse***
  Set the Polarity of the clock's pulses. This does not affect the polarity of clock pulses triggered by a bind to an axis or event.

- ***Bind Clock to Axis / Bind Clock to Event***
  Allows a Clock to be bound to the read of an axis. Clocks may also be bound to waveform events. The madlib.dll documentation (Madlib_*_*.doc) should be referenced for complete information on the effect of the different binding options.

Confirm or Reset the ISS Configuration
The Confirm/Reset area is shown in Figure 4.1 (area 3). Click "Confirm Changes" and Nano-Route®3D will begin communicating the on-screen ISS configuration to the Nano-Drive®. Click "Reset all to Defaults" to return the on-screen ISS configuration to the most recent confirmed state; however, "Confirm Changes" still must be clicked to communicate these settings to the Nano-Drive® (the reset settings shouldn't need to be re-confirmed).

Configure ISS Commands for the Beginning and End of each Scan
Nano-Route®3D provides a means to program a pre/post-scan pulse sequence via the four available ISS digital outputs (Figure 4.1, area 4). A checked box in the left column represents that the corresponding ISS output will pulse once before the scan begins. A checked box in the right column represents that the corresponding ISS output will pulse once after the scan has finished. If pulsing multiple outputs, specify the order via controls at the right of the checkbox; available options are 1st, 2nd, 3rd, and 4th.

- ***Detailed ISS Control***
  In the event that the basic pre/post scan options (explained above, under the heading "Programmatic ISS Control") are insufficient to provide digital setup/configuration information to your hardware, click this button to expand your pre/post scan ISS pulse options. Check a box in the row of the desired ISS output and the column of the desired time/order of the pulse. Enter values into the Numeric Controls within the "milliseconds" row to control the pulse length of the pulses in the column.

Pulse any of the ISS clocks
Clicking these buttons (Figure 4.1, area 5) will generate a 250 ns pulse on the corresponding clock. The polarity of these pulses can be configured within the Main ISS Configuration Interface. By default these pulses will be low-to-high. Pulsing a clock will set its idle polarity to low; Nano-Route®3D will reflect this.

Chapter 5: Build Graph Image

After the Nano-Drive® has completed a Route (scan), use the "Build Graph Image" page to configure the graphical illustration of the retained ADC and DAC data. From the "Build Graph Image Page" the user has two options for exporting data from Nano-Route®3D; Nano-Route®3D will generate a text file containing the x and y coordinates for each point currently displayed on the graph, or, the Nano-Route®3D graph image can be printed directly using the *print-screen* key.

The Labeled Functions of the "Build Graph Image" Page

1. These tabs provide access to the separate pages of this application.*
2. A graphical display for the DAC and ADC data. **
3. Configure the various display options for the graph. **
4. Select which scan to show; turn on/off certain plot options. **

* This function is available from all pages of the application
** This function is explained in further detail below

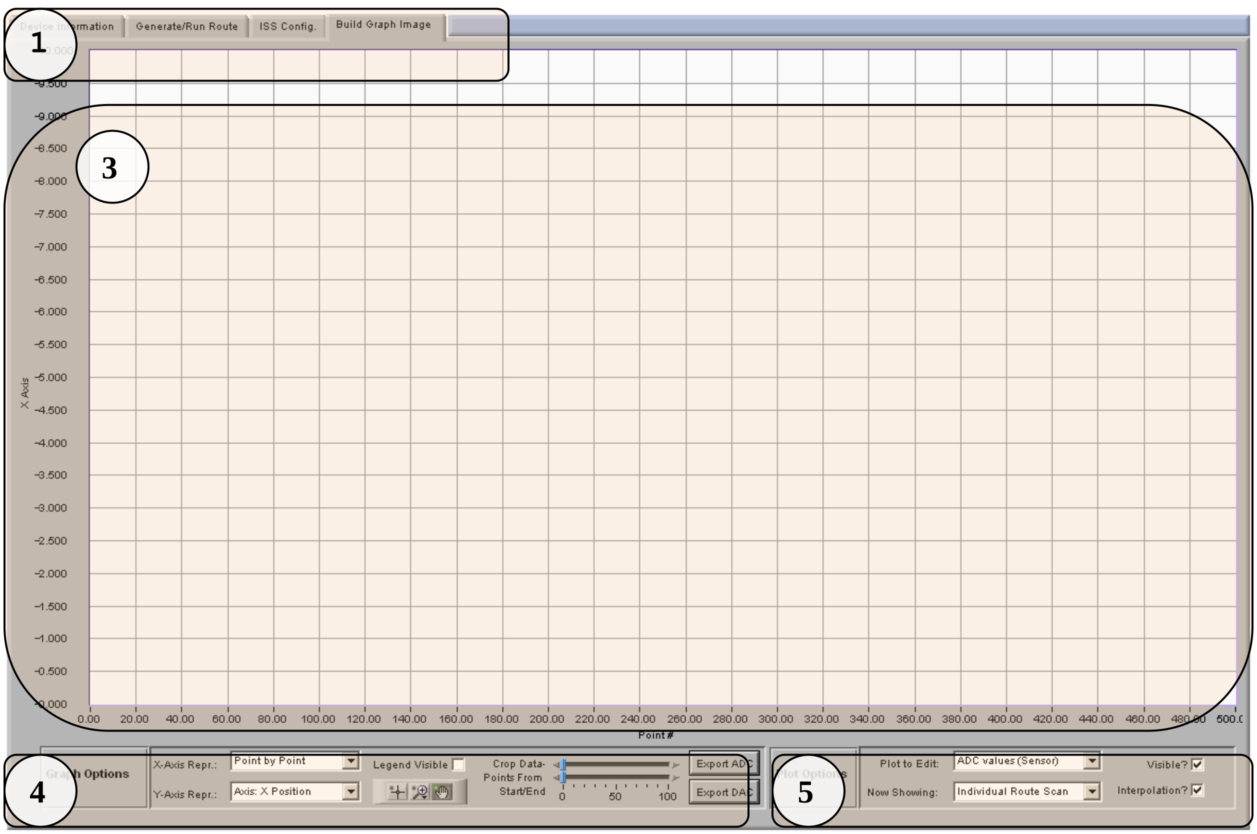


Figure 5.1 – The Build Graph Image page with areas of interest highlighted.

A Graphical Display for the DAC and ADC Data

In Figure 5.1 (area 3), the DAC (input) data is displayed in green; the ADC (sensor) data is displayed in blue. Here the user is free to manipulate the graph of these plots using both the conventional LabVIEW options (right-click the graph to access these options) and the custom options filling the two bottom panels.

Graph Options

The graph options are located in the lower left corner of this page (area 4). The parameters allow the user to customize the way the graph is read, remove unnecessary datapoints, or toggle the visibility of the plot legend.

- ***X-axis / Y axis Representation***
  The X and Y axes refer to the X and Y axes of the graph. Within the pull-down menus, references are made to the axes of the Nano-Drive®. Use the pull-down menus to configure the way the graph is read; i.e. plot the ADC data vs. time, vs. data-point number, or vs. ADC data from another axis.

- ***Crop Data-Points from Start/End***
  Use these slider bars to remove data-points from the graph. The data-points are removed from both the DAC and ADC plots. The data-points removed from either end cannot exceed 100.

- ***Export Data-Points***
  Left-click this button to export the Y-values of each plotted point of the Sensor and Command, into two separate data files which can be opened by any text editor. Each value is terminated with an end-of-line character for easy integration into an external graphing program.

Plot Options

Use the "Plot to Edit:" pull-down menu (Figure 5.1, area 5) to select a plot, then left-click either the interpolation or visibility check-boxes to toggle these options. Use the "Now Showing:" pull-down menu to select between plotting the returned raster scan ADC values, or the "Run Route"/"Run all Routes" returned ADC values.

- ***Interpolation***
  Draws a line through all the datapoints of a plot on the graph. The features of the line drawn do not indicate the actual motion of the stage.

Chapter 6: Choosing an Analog-to-Digital (A/D) Rate

The A/D rate specifies the rate at which data-points will be issued to the Nano-Drive®. Nano-Route®3D generates Paths to span user specified amounts of time by stringing together evenly-spaced datapoints, each datapoint representing a Period of the A/D rate. Therefore, the number of data-points within the Path is equal to the time span of the Path divided by the A/D rate.

Supported A/D Rates for Each Motion Command Method

The chosen A/D rate determines the available motion command methods (single-write, waveform acquisition, raster scan). Below is a reference table to assist in the selection of an appropriate A/D rate and motion command method. A description of each motion command method is shown in Table 6.1 below.

Motion Comm. Method	16-bit Supported A/D Rates	20-bit Supported A/D Rates
Single Read / Single Write	-Greater than or equal to 2ms -Increments of 1ms	*- same as 16-bit -*
Waveform Acquisition	-Less than or equal to 5ms -Greater than or equal to 33us*	-Less than or equal to 20ms** -Greater than or equal to 267us*
Run All Routes	-Greater than or equal to 6ms	*- same as 16-bit -*
Raster Scan (without using WF Acquisition)	-Set A/D rate to 1ms -Add delay using control within raster scan panel	*- same as 16-bit –*
Raster Scan (WF Acquisition)	-Less than or equal to 5ms -Greater than or equal to 33us* -DAC and ADC rates individually specified	- Less than or equal to 20ms** -Greater than or equal to 267us* -DAC and ADC rates individually specified

Table 6.1 – Supported communication methods and A/D rates.

** Fastest rate varies according to Nano-Drive® features. Refer to Nano-Drive® manual for clarification.*
*** This parameter may be limited by Nano-Route®3D and may not meet the specifications of the nanopositioner*

- ***Single Write / Single Read***
  This is the standard motion command method (i.e. when no motion command method has been specified, the Single Write / Single Read method is used). With this method, each datapoint represents two interactions with the Nano-Drive® -- write the command, then read the position. Each interaction with the Nano-Drive® requires one millisecond. Artificial delay is added for A/D rate requests slower than two milliseconds -- the artificial delay is added in millisecond increments.

- ***Waveform Acquisition***
  Check the "WF acq" checkbox to enable this motion command method. Clicking the "Run Route" button will now load the entire Route into Nano-Drive® onboard memory; the Nano-Drive® can now command each datapoint with no further interactions with the CPU, removing the delays associated with USB communication. This motion command method cannot be used to drive more than a single axis at a time.

- ***Run All Routes***
  All axes are commanded through their Routes. The X, Y, then Z, axes *Single Write* their first datapoint, then each axis takes a turn *Single Reading*; beginning with X, then Y, then Z. This sequence continues until all datapoints have been written, completing the motion command. Because each transaction (Single Write or Single Read) requires one millisecond, each iteration of this sequence occurs over a minimum six millisecond time span (allowing time for all active axes to write and read).

- ***Raster Scan***
  A/D rate is ignored. Set the "ms/dpts" control to dpts. Artificial delay is added between data-points using the "Add delay" control within the Raster Scan panel. With zero Pixel delay the A/D rate is slightly faster than two milliseconds per point.

Troubleshooting

The chosen A/D rate determines the available motion command methods (single-write, waveform acquisition, raster scan). When the user attempts to run a scan at an unsupported A/D rate an error message pops-up to explain the problem. A table of common error messages and their solutions are shown in Table 6.2 below.

Error	Solution/Explanation
"The A/D rate must be set to 6ms to scan all routes. Correct this error and try again."	An attempt has been made to "Run all Routes", but with insufficient time for Nano-Route®3D to write/read <u>*each*</u> axis. A single write takes 1 ms, as does a single read. Nano-Route®3D assumes a three axis scan is taking place giving the 6ms minimum mentioned in the error message. Reset the A/D rate to 6ms.
"The A/D rate must be equal to, or greater than, 2ms per point when not using Wave Acquisition. Correct this error and try again."	When the "WF Acq." checkbox is <u>*unchecked*</u>, Nano-Route®3D assumes you want the data-points issued one at a time (single write and single read). Since each single write and single read occurs over a minimum of two milliseconds, an A/D rate of less than 2 milliseconds is not possible. Use Waveform Acquisition to achieve A/D rates faster than 2 milliseconds per point.
"When performing WaveForm Acquisition the A/D rate cannot exceed 5ms. Correct this error and retry."	When the "WF Acq." checkbox is <u>*checked*</u> Nano-Route®3D expects the Route is suited for Waveform Acquisition. A/D rates slower than five milliseconds are not supported by Waveform Acquisition within Nano-Route®3D.

Table 6.2 – Common error messages and their solutions

Chapter 7: Applying Functions

For simple Path creation, Nano-Route®3D provides the ***"Remain at"*** and ***"Ramp to"*** methods which require only three input parameters; displacement (in microns), the A/D rate, and duration (in milliseconds or datapoints) of the path. Nano-Route®3D automatically divides the path into a series of individual command points and graphs the result as the Path Prototype. When more complex motion is required, Nano-Route®3D can interpret user-specified functions. These functions can be entered in a text box on the "Generate/Run Route" page (see Figure 3.1, area 4).

Creating a Path According to a Function

Nano-Route®3D allows the entering of user-specified one-dimensional formulas which are of the format $Y = f(X)$. The X value for each point is assigned according to the chosen Path creation method. Paths can be created as a one dimensional array of points ("Apply Point Func:") or as a time based function ("Apply Time Func:"). Position command values (Y) are calculated for each X value according to the input function specified. Tables 7.1 and 7.2 show example input formulae with their expected output values. Note that the point function creates point values, whereas time function creates time based values.

** Note: All Trigonometric function arguments assume radian values (not degrees).*

The Two Path Creation Methods

Complex Path creation is achieved via the "Apply Point Func:" and "Apply Time Func:" methods. These methods differ in how they interpret the value of the variable X.

- ***Apply Point Func:***
  The X value at each data-point is assigned according to the data-point's counted position from left to right; i.e, X = 0, 1, 2, 3, 4 …, Number_Of_X -1. Position command values, Y, are calculated for each X value according to the input function. The function below defines a sine wave using the "Apply Point Func:"

  *Sin (pi(2) * X * frequency * Analog-to-Digital rate)*

- ***Time Func:***
  The X value at each data-point is assigned according to the data-point's counted position from left to right (i.e. 0, 1, 2, 3, 4 …) divided by the total number of data-points which fit within one second. Position command values, Y, are calculated for each data-point according to the input function. The function below defines a sine wave using the "Apply Time Func:"

  *Sin (pi(2) * X * frequency)*

Using the "Apply Point Func" method	
Function entered	**Position Command Values (Y)**
2*x	2, 4, 6, 8, 10, 12, 14, 16, …
10*sin(x)	8.414, 9.093, 1.411, -7.568 …
(x+1)^-1 + pi(2)	7.28, 7.58, 7.61, 7.53, 7.48 …

Table 7.1 – Values generated using the point function path method

Using the "Apply Time Func" method	
Function entered	**Position Command Values (Y)** *(using an arbitrary 1ms A/D rate)*
2*x	0, 0.002, 0.004, 0.006, 0.008 …
10*sin(x)	0, 0.01, 0.02, 0.03, 0.04 …
(x+1)^-1 + pi(2)	7.28, 7.28, 7.28, 7.28, 7.27 …

Table 7.2 – Values generated using the time function path method

Formula Syntax

Below is a list of available operators and a table of function prototypes usable within the formula. Note that no warning is generated in the event Nano-Route®3D cannot interpret the entered formula. Instead, the Path Prototype will remain flat at the initial position for its duration, ignoring all aspects of the function.

Operator	Description	Example
+, -, *, /, ( )	Basic arithmetic operators	*(x * 2) / (x + 1) – 5*
pi(1), pi(2), pi(3), … pi(n)	Pi multiplied by n	*Sin(pi (2))*
^	Exponential operator	*x ^ 2*

Table 7.3 – Simple operators available to use within the formula

Function	Description
abs(*x*)	Returns the absolute value of *x*.
acos(*x*)	Computes the inverse cosine of *x* in radians.
acosh(*x*)	Computes the inverse hyperbolic cosine of *x*.
asin(*x*)	Computes the inverse sine of *x* in radians.
asinh(*x*)	Computes the inverse hyperbolic sine of *x*.
atan(*x*)	Computes the inverse tangent of *x* in radians.
atanh(x)	Computes the inverse hyperbolic tangent of x.
ceil(*x*)	Rounds *x* to the next higher integer (smallest integer *x*).
ci(*x*)	Evaluates the cosine integral for any real nonnegative number *x*.
cos(*x*)	Computes the cosine of *x*, where *x* is in radians.
cosh(*x*)	Computes the hyperbolic cosine of *x*.
cot(*x*)	Computes the cotangent of *x* (1/tan(*x*)), where *x* is in radians.
csc(*x*)	Computes the cosecant of *x* (1/sin(*x*)), where *x* is in radians.
exp(*x*)	Computes the value of *e* raised to the *x* power.
expm1(*x*)	Computes one less than the value of *e* raised to the *x* power ((*e*^*x*) – 1).
floor(*x*)	Truncates *x* to the next lower integer (largest integer *x*).
getexp(*x*)	Returns the exponent of *x*.
gamma(*x*)	Evaluates the gamma function or incomplete gamma function for *x*.
getman(*x*)	Returns the mantissa of *x*.
int(*x*)	Rounds *x* to the nearest integer.
intrz(*x*)	Rounds *x* to the nearest integer between *x* and zero.
ln(*x*)	Computes the natural logarithm of *x* (to the base of *e*).
log(*x*)	Computes the logarithm of *x* (to the base of 10).
log2(*x*)	Computes the logarithm of *x* (to the base of 2).
si(*x*)	Evaluates the sine integral for any real number *x*.
sec(*x*)	Computes the secant of *x*, where *x* is in radians (1/cos(*x*)).
sign(*x*)	Returns 1 if *x* > 0, returns 0 if *x* = 0, returns –1 if *x* < 0.
sin(*x*)	Computes the sine of *x*, where *x* is in radians.
sinc(*x*)	Computes the sine of *x* divided by *x* (sin(*x*)/*x*), where *x* is in radians.
sinh(*x*)	Computes the hyperbolic sine of *x*.
spike(*x*)	Generates the spike function for any real number *x*.
sqrt(*x*)	Computes the square root of *x*.
step(*x*)	Generates the step function for any real number *x*.
tan(*x*)	Computes the tangent of *x*, where *x* is in radians.
tanh(*x*)	Computes the hyperbolic tangent of *x*.
square(x)	Generates a square waveform.

Table 7.4 – Table of function prototypes usable within the formula

Troubleshooting: Problems applying a function

Error	**Explanation/Solution**
"My Path Prototype appears as a flat line"	Two possible explanations. Either an invalid function has been used (see Table 7.4 for valid functions) or an invalid argument has been used. Check your function.
"My Path Prototype appears incomplete"	If using the Point Function method there is an insufficient number of data points to complete your function. Either alter the user specified parameters or increase the number of data points. If using the Time Function method, the duration of your plot is too short. Either alter the user specified parameters or increase the duration.

Table 7.5 – Common troubleshooting questions.

Chapter 8: Generating a Z-Stack

This chapter describes how to use Nano-Route®3D to create a Z-axis stack of images, a type of Route common for cellular imaging. In these and other applications, a single Z-axis stepping motion is used to obtain individual XY plane images that are later recombined to form a three dimensional image. These images are known as a Z-stack, or staircase motion, and require moving in a given number of specific step sizes with a wait, or dwell, period at each step. Pairing function defined Path creation with the "Relative start" feature, Nano-Route®3D provides a flexible interface for defining Z-stack motion.

Section 8.1 - Z-Stacks in Nano-Route®3D

To create a Z-stack in Nano-Route®3D, the 'floor' function (see Table 7.4) is employed in the ***'Point Func'*** method of path creation for a single-axis scan. An explicit formula used in Nano-Route®3D will generate the desired Z-stack motion.

8.1.1 - Determining the Input Formula

To determine the exact formula, first define the following parameters of the Z-stack:

- ***Parameters***
  Start position (in microns)
  End position or travel range (in microns)
  Number of steps/stacks
  Step-size (in microns)
  Dwell time / delay time at each step (in ms)

- ***The Z-Stack Function Inputs***
  The first step is to utilize the single-axis scan template and determine the appropriate values for the explicit function. The input formula will have the following format:

*(step-size)*floor(x / (#dpts per step))+(start position)*

or

$$A*floor(x / B) + C,$$

where *floor(x)* is an available function (see Table 7.4)

Z-Stack Input Formula Format: A * floor(x / B) + C	
Parameter	**Definition**
A	step-size (in microns)
B	Number of dpts per step
C	start position (in microns)

Table 8.1 – Z stack input formula format

- ***Determining the Function Inputs***
  To determine parameter B (shown in Table 8.1) for input into Nano-Route®3D, use the following calculation:

  # dpts per step [B] = (dwell time per step) ÷ (A/D rate)

  Note: The A/D rate is arbitrarily selected and may depend on the step-response of the nanopositioner. Typical values are 1 or 2ms.

  Then determine the total number of points required to generate the path by using the following equation:

  *Total # dpts = ((# steps+1) * B)*

8.1.2 - Creating the Z-Stack

We now have the required information to input into Nano-Route®3D for path generation.

1. Change the Path model to ***"Apply Point Func"*** using the pull-down menu.

2. Input the Total number of datapoints in the ***"over the interval of"*** field; ensure that ***"dpts"*** is selected on the drop-down menu.

3. Enter the function using the format defined in this section and the calculated values above.

4. Make sure ***"WF Acq."*** box is checked.

5. Verify the temporary path shown is correct before accepting the path into Nano-Route®3D.

Section 8.2 - An Example Z-Stack in Nano-Route®3D

Perform a Z-stack between 10µm and 50µm position using 0.5µm step-size with 50ms dwell time at each step. We choose an arbitrary A/D rate of 2ms for this example.

Total # steps = 80 steps *(travel range of 40*µm */ 0.5*µm *step-size)*

A = 0.5µm
B = 25 dpts per step *(50ms / [2ms/pt A/D rate])*
C = 10µm

Total #dpts = 2025 *([80 steps + 1] *25 dpts per step)*

Formula entered:

*0.5*floor(x / 25) + 10*

or

*0.5*floor(x*0.04) + 10*

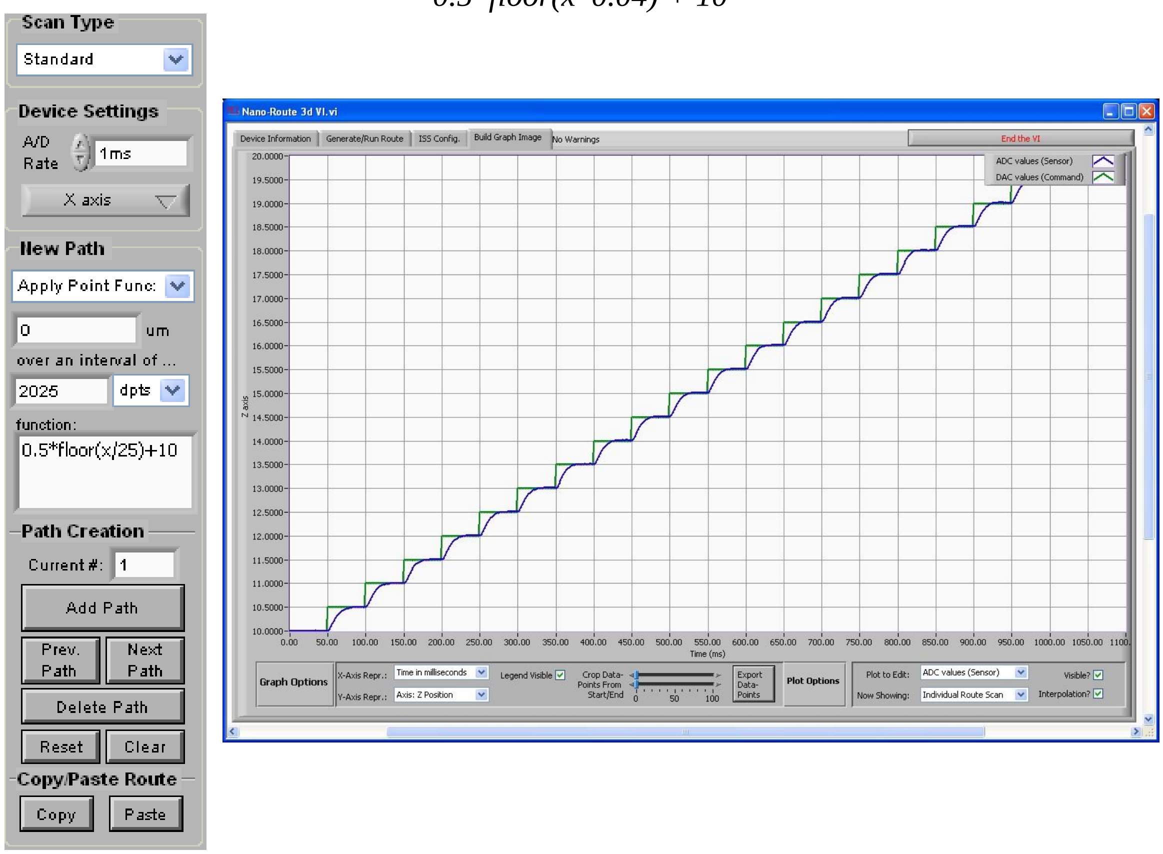


Figure 8.1 – Template/Path Settings menu for the example (left) and the resulting path (right). The path shows the Z-axis range from 10µm to 20µm only for clarity.

Chapter 9: Generating a Raster Scan

There are several ways to generate a raster scan using Nano-Route®3D and a Mad City Labs nanopositioning system. Line scanning speed and the total time taken for a raster scan are affected by the values chosen for the following Nano-Route®3D parameters; steps (pixels) per line, lines per frame and frames per volume; and other variables that are discussed later in this chapter. In order to generate a raster scan you must be on the "Generate/Run Route" page.

Section 9.1 - Parameter Settings for Raster Scanning

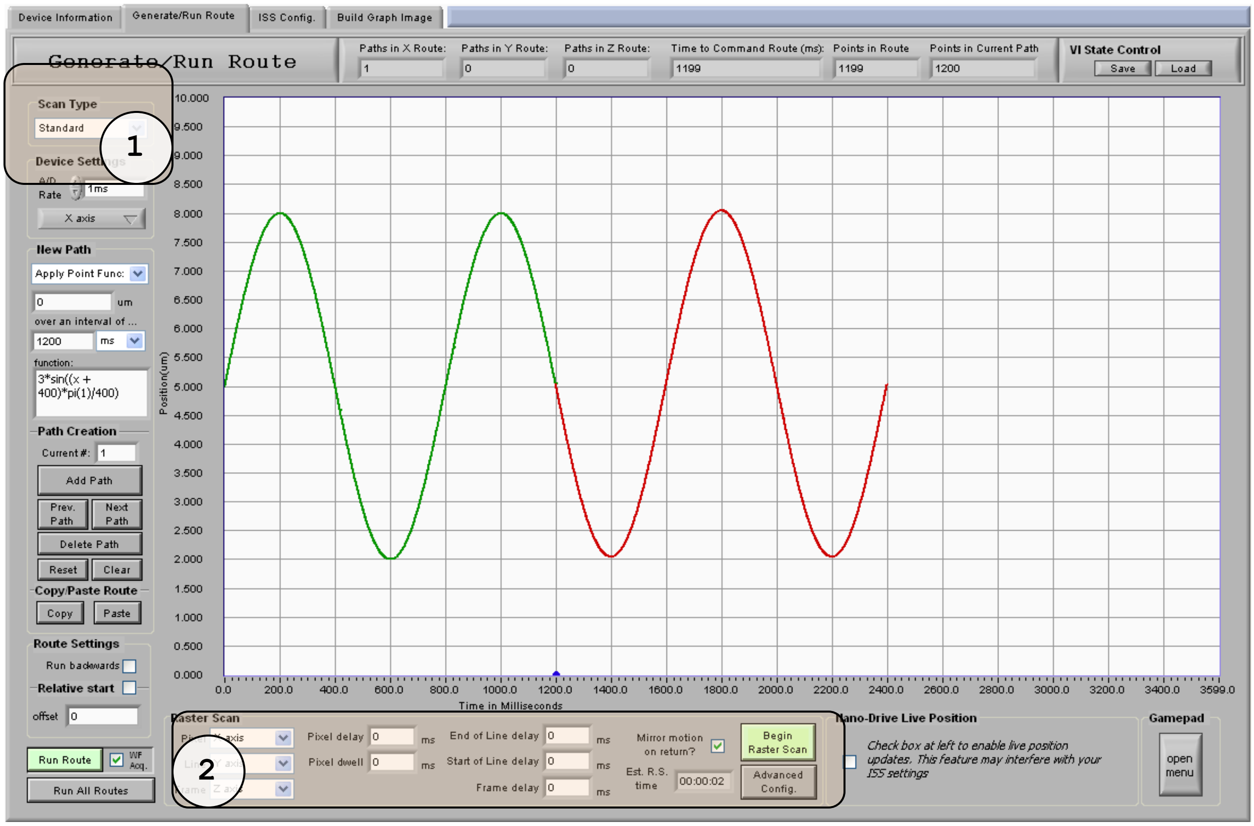


Figure 9.1 – Generate/Run Route page showing the menus relevant to generating a raster scan. A discussion of areas (1) and (2) is below.

- ***Template/Path Settings Menu (1)***
  Select "Raster Scan" in the drop down ***Template*** menu

  Under ***Path Settings***, use "Remain at", "Ramp to", "Apply Time Func.", and "Apply Point Func." to create the raster routes.

- ***Raster Scan Menu (2)***
  The Raster Scan menu allows the user to switch between axes and edit using the XYZ drop down menus.

  Pixel is the axis that moves to increment pixels. Typically this is the fastest axis, usually the X-axis of the nanopositioning stage for a one dimensional scan

Line is the axis that moves to increment lines. Typically this is the Y-axis for a two dimensional scan

Frame is the axis that moves to increment frames. Typically this is the Z-axis for a three dimensional scan.

Timing aspects of the raster scan are set using the pixel delay, line delays, and frame delay.

Pixel delay is the delay (in milliseconds) after a command to the designated pixel axis, and before the pixel axis position is read.

End of line delay is the delay (in milliseconds) after the last pixel command on a line, and before the line axis increments to the next line (or the next frame axis command).

Start of line delay is the delay (in milliseconds) after a line axis command, before the next pixel axis command (or the next frame axis command).

Frame delay is the delay (in milliseconds) after a frame axis increment command, before the next pixel axis command

Mirror motion on return
When this is checked Nano-Route®3D scans alternate directions for each line. This may be faster than returning to the same side to start each line, depending on how the scan is set up

Advanced Configuration Options
Nano-Route®3D provides the ability to use Waveform Acquisition as the method for commanding and reading the designated pixel axis of the raster scan. Click this button to access settings which describe the waveform, and to specify whether Waveform Acquisition should be used during the scan. More information on this can be found in Section 9.2, under the heading; *Wave Acquisition to Command and Read the Pixel Axis*.

Section 9.2 – Additional considerations when generating raster scans

In addition to the user specified parameters in Nano-Route®3D listed above, there are other factors which can affect the generation and characteristics of your raster scan.

Constant Velocity
Constant Velocity can be achieved by setting the total commanded scan area to be larger than the desired imaged area. This guarantees that any acceleration regions are outside the area of interest. If working at high speeds, factor in the frequency response of the stage.

How Step Response Time Affects Raster Scanning

The step response time is defined as the time it takes the stage to move from 10% to 90% of the commanded motion. Step response time is independent of the commanded step size. It is important to note that your nanopositioning stage will have a different step response time for each axis. Step response information was shipped with your nanopositioning system (Certificate of Performance), however if you are unable to find this document contact Mad City Labs with your serial number(s) and model name. *It is particularly important* to know how long it takes the stage to settle to the commanded position to your precision specificatons. This varies from system to system depending on the system configuration and your application.

Because the step response time is approximately the same, independent of the size of the step, a motion involving multiple steps will take longer than a motion that involves fewer steps. For a scan which requires a certain amount of dwell time on each pixel, set the pixel delay to longer than the step response of the stage. For continuous motion set the pixel, line, or frame delays to less than the step response of these axes.

How Gain vs. Frequency Affects the Scan Size of a Raster Scan

Each system has a particular relationship for gain vs. frequency that resembles a low-pass filter response. The motion achieved by the series of commands sent to the stage can be thought of as a waveform (i.e. the pixel axis may be repeatedly commanding ramps with a short time between ramps, which could be thought of as a modified triangle wave). The higher the frequency of this waveform, the smaller the output amplitude will be. This means that a 100 micron motion command could receive a 50 micron response, depending on the frequency of the command waveform. The 3dB point of the system (where the stage's motion is approximately 70% of the input) is related to the step response. If you have questions about this, contact Mad City Labs.

Wave Acquisition to Command and Read the Pixel Axis

Nano-Route®3D provides the ability to use Waveform Acquisition as the method for commanding and reading the designated pixel axis of the raster scan. From the *Generate/Run Route* page, with the "Raster Scan" template selected, click the "Advanced Configuration Options" button to access settings which describe the waveform, and to specify whether Waveform Acquisition should be used during the scan.

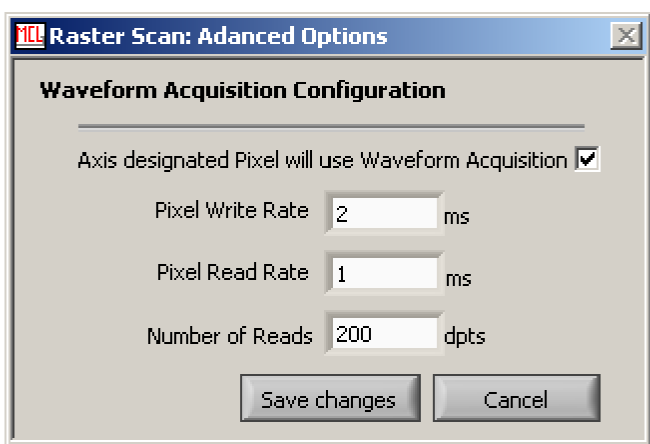


Figure 9.2 –Waveform acquisition pop-up menu.

Section 9.3 - Examples of Different Raster Scans

The following example will demonstrate how to implement a 30um x 20um x 10um volume raster scan with 100 lines per frame and 50 frames per volume. The example outlines three different line scan methods in achieving the same raster scan.

The system in this example takes t_1 (ms) to complete a full step on the pixel axis, t_2 on the line axis, and t_3 on the frame axis.

Raster Scan Example: **Definition of Variables**	
Parameter	**Definition**
t_1	milliseconds to complete a full step on the pixel axis
t_2	milliseconds to complete a full step on the line axis
t_3	milliseconds to complete a full step on the frame axis

Table 9.1 – Raster scan variables

9.3.1 – High speed line scan method.

The fastest way to do this scan would be to command a single 30um step for each line on the ***pixel*** axis. To achieve this we command the pixel axis to "Ramp To" 30um over 2 data points (dpts). Two data points indicates that there will be two data points on the line: the start point and the end point. The ***pixel delay*** determines how long LabVIEW will wait between position commands on the pixel axis. For continuous motion, this should be set to a value less than or equal to step response time: at least a few ms less than t_1. If the pixel delay is greater than or equal to t_1, the stage will slow down at the end of each step. In the two point example, the line scanning speed will be about t_1. At the end of the line, the next line is stepped to by moving the line axis. On the ***line*** axis we should command a "Ramp to" 20um over 100 dpts. On the ***frame*** axis we should command a "Ramp to" 10um over 50 dpts.

- Checking ***mirror motion on return*** will mean the pixel axis does not have to move to reach the starting point for the new line. The scan will proceed by scanning opposite directions on each line.
- Uncheck ***mirror motion on return*** if the line scans must start from only one end of the pixel axis. For the fastest speed, set the start of ***line delay*** or ***end of line delay*** to 0 ms, so that the line axis moves during the last step of the line or the first step of the next line.
- In two dimensional images where it is not desirable to have the pixel and line axes moving at the same time set the ***end of line delay*** to at least t_1 and the ***start of line delay*** to at least t_2 to give each axis time to settle before the other one moves.
- In three dimensional images where it is desirable to have only one axis moving at a time, set the ***frame delay*** to t_3. If it does not matter if the frame

axis moves while the two dimensional scan is still in progress, then set the ***frame delay*** to 0 ms.

- Speed up the scan by setting the ***line delay*** and ***frame delay*** to less than the time it takes the corresponding axis to do a full step. WARNING! This may result in multiple axes moving at once.

9.3.2 – Step and settle line scan method.

To step and settle at each pixel, choose more than 2dpts on the ***pixel*** axis. If a specific dwell time on each pixel (t_d) is required, then set the ***pixel delay*** time to a value greater than t_1+ t_d. This ensures that the stage has time to arrive at the commanded position and remain there for the dwell time before moving to the next pixel. This will mean that the line scanning speed is reduced to:

$$(\text{number of data points}* (t_1+ t_d)),$$

resulting in line scans that are significantly slower than described in Option 1 above.

To complete the raster scan you will need to repeat the steps for the line and frame axis described in section 9.3.1.

9.3.3 – Fixed speed line scan method

There are two different methods to achieve a specific line scanning speed of t_{scan} (ms) per line:

- To stop on each pixel for a specified dwell time; divide (t_1+ t_d) into t_{scan} to find the total number of data points required for the line scan (remember to add one data point for the starting point).
- To move continuously; divide the step response time into t_{scan}. Waiting t_1 ms or more between each data point may result in an unsmooth motion (since the stage will start to settle before it moves again).

To complete the raster scan you will need to repeat the steps for the line and frame axis described in section 9.3.1.