Software for Generating RTC® Correction Files

correXion pro

Software Version 1.0.3

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Contents

1 Introduction

This user manual describes SCANLAB's correXion pro scan field calibration tool and its usage in creating RTC® correction files.

Read this user manual in its entirety before attempting to install or use correXion pro.

If you have questions regarding this manual's contents, then contact SCANLAB.

1.1 Scope of Delivery

The software package with the correXion pro program is normally supplied on CD. All required files reside in one directory:

- Cor_1to1.ct5
- correXionLib.dll
- correXionPro.exe
- libiomp5md.dll
- Template.dat

1.2 Manufacturer

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1.3 System Requirements

Hardware

Full usage of the correXion pro program requires that the scan system be controlled by an RTC® board installed in an IBM-compatible PC. The RTC® board and its driver must be correctly installed (see RTC® manual). The RTC® board must be properly connected to the scan system

Operating System

correXion pro is a dialog-based Win32 application usable with the following Microsoft operating systems:

- MS WINDOWS 2000
- MS WINDOWS XP
- MS WINDOWS Vista
- MS WINDOWS 7
- MS WINDOWS 8

Driver

An OpenGL 1.1-compliant graphics driver is required on the control PC.

2 Image Field Correction

SCANLAB's scan systems implement image field correction with the help of correction files. The correction file contains all information required for scanning within a plane (or within a working volume in the case of 3D correction files). When calculating control values, the RTC®PC interface board takes the correction file's contents into account to compensate the image field distortion inherent in two-mirror systems (including optics).

RTC®correction files are binary files with the file extension ".ctb" (**c**orrection **tab**le) for RTC®2, RTC®3 and RTC®4 PC interface boards and ".ct5" (**c**orrection **t**able**5**) for RTC®5 interface boards.

2D correction files consist of two adjoining tables. A 3D correction file appends supplemental information after these two tables. Each of the two tables contains correct digital control values to be output by the RTC®board to one of the scan system's galvanometer scanners for predefined points within the image field. These predefined points represent a 65·65 or 257·257(1) array of a quadratic grid superimposed over the image field (on the (z=0) plane for 3D correction files).

The output values for an arbitrary point within the image field are calculated by interpolation of the corrected values of neighboring grid points.

By default, SCANLAB's correction files are calculated from general system data (e.g. mirror geometry, calibration factor, objective specifications). Individual system properties and alignment errors aren't taken into account.

If your application needs correction files precisely reflecting your particular system's properties, then consider using SCANLAB's correXion pro program. It generates RTC® correction files using test measurement data and an RTC® original correction file. correXion pro calculates how much the test data deviates from that of the original correction file and then generates a high-precision correction file. The RTC® software packet's 1:1 correction file can be used to mark the test points, too.

(1) 65·65 points are generated for creating ctb correction files (for RTC®2-, RTC®3 and RTC®4 boards), whereas 257·257 points are generated for creating ct5 correction files (for RTC®5 boards).

correXion pro can create ctb correction files for RTC®2, RTC®3 and RTC®4 PC interface boards, as well as ct5 correction files for RTC®5 PC interface boards.

Note

correXion pro is compatible with SCANLAB's correXion and correXion5 programs.
correXion pro can load data files created with correXion and correXion5 (for details, see chapter 4.7, page 20).

3 Installing correXion pro

- Insert the software CD into the optical drive of the PC in which your RTC® board is installed.
- With Windows Explorer, open the CD's directory containing all the software package's files.
- Copy all of this directory's files to any desired directory on your PC.

Caution!

After installation, all of the software package's files must reside in the same directory.

4 Creating RTC® Correction Files

4.1 General Procedure

The correXion pro program can be operated in dialog mode via a graphical user interface (GUI) or in silent (background) mode. Follow the test measurement instructions and ensure that your data file is correctly formatted.

- Use your scan system and the RTC® software packet's original correction file to mark test points within the image field (see chapter 4.2, page 7).
- Measure the coordinates of the resulting marked test points. If you require very high accuracy, then use a measurement microscope (see chapter 4.2).
- Use an editor to create a data file containing the measurement data (see chapter 4.3, page 8).
- If you haven't specified a path to the original correction file (that you used for marking the test points), then copy the file into the same directory your data file resides in.
- Start the correXion pro program to create a new RTC® correction file based on both your data file and the original correction file (see chapter 4.5, page 11 and chapter 4.6, page 18).

4.2 Marking and Measuring Test Points

- Use your scan system with an appropriate correction file to mark test points (no more than 10,000 points) at any desired locations within the image field.
  If you're using a 3D correction file, then mark the points in the (z = 0) plane (2).
- Suitably set dynamics-related parameters so that the test points' target positions will be reliably reached.
- Mark the test points only after warm-up (30 to 60 minutes). During warm-up, the galvanometer scanners should be moved so that the typical working temperature is reached.
- Make sure your point-marking software loads the correction file without scaling, rotation, and offset.
- The digital control values (in [bit]) required for marking the test points must be known (if necessary, they can be obtained via the calibration factor).
- Measure the (x|y) coordinates (in [mm]) of the resulting test points. Select the desired mid-point of the image field as the origin (0|0) of the measurement coordinate system.

  The default orientation of the axes for RTC® boards is in accordance with the following convention:
  - The Y-axis points in the opposite direction of the entry beam.
  - The Z-axis points in the opposite direction of the exit beam.
  - The X-axis is determined by the righthandness of the coordinate system (galvanometer 1 deflects the beam in the y direction, galvanometer 2 in the x direction).

  If you use a different axis convention for measuring the test points, then the (x|y) coordinates produced with the new correction file will also be based on your different axis convention.

(2) The calibration procedure described here is only appropriate for creating 3D correction files if the intended working distance and calibration for the new and old correction files are identical.

Note

Under optimal conditions – within a typical square image field having a side length of 100 mm – positional accuracy in the single-digit micrometer range is attainable. The positional accuracy achieved depends primarily on the following factors:

Substrate and mechanical stability:
The substrate's temperature, and hence its dimensions, change slightly during the marking process. And substrate surface unevenness affects calibration accuracy, too. These effects are typically non-linear.

Temperature:
Calibration temperature and operating temperature should be identical. If not, then expect primarily gain and offset effects.

Accuracy of measuring instruments:
The value of the "tolerance" parameter (see page 9 and page 12) should be appropriate for the accuracy of the applied measuring process.

Number of test points:
Generally, more test points result in higher calibration precision. However, beyond a certain count, expect diminishing returns in terms of positional accuracy. In specific cases (e.g. a square image field with a side length of 100 mm), a grid of 11·11 points is sufficient for achieving positional accuracy with a standard deviation of 1.5 μm upon the first iteration (but don't apply this generally – each application requires its own count and distribution of test points).

Number of iterations:
One or two iterations are often sufficient. If deviations remain disproportionate after two iterations, then you should check the factors described here and make any needed changes.

4.3 Data File Structure

Use an editor to create a data file and give it a filename with the extension ".dat".

The data file will contain the coordinates of the marked test points and parameters and directives for generating the correction file via correXion pro. The parameters and directives must be listed one-per-line at the beginning of the data file. The measured values (one line per test point) must be listed at the end of the file. Within each section of the file, the order of items that you list can be arbitrary.

Both the decimal point and the decimal comma are acceptable as decimal separator characters. Comments must be preceded by a slash (/). Blank lines are ignored.

(The following example data file is included in the software package: "Template.dat".)

Parameters

- **OldCTFile**:
  Path or name of the original RTC® correction file (example: OldCTFile = cor_1to1.ct5)
- **NewCTFile** (optional in dialog mode):
  Path or name of the new RTC® correction file (example: NewCTFile = NewCorTable.ct5)

Notes

- The filename extension ct* – i.e. ctb or ct5 – must be identical for both the original and new correction files.
- correXion pro evaluates the filename extension to determine whether it's an RTC®2/RTC®3/RTC®4 or RTC®5 table.
  (The GUI adapts appropriately, see chapter 4.5, page 11).
- If you only supply names (without paths) of the original and new correction files, then the data file directory will be automatically selected. Here, be sure to copy the original correction file into the same directory as the data file before starting the program.
  Otherwise, the program will abort with a "File not found" error.

- **Tolerance** (optional):
  The Tolerance parameter determines how much (in [µm]) the calculated values may deviate from the measured test points.
  If Tolerance = 0, then the measurement points will be interpolated and the fit passes exactly through all measurement points.
  – Default: 0
  (Example: Tolerance = 5.0)
- **NewCal** (optional):
  The parameter NewCal specifies a calibration factor in [bit/mm] to be taken into account when correXion pro calculates the new correction file (also see "Parameter Settings", page 12).
  If the NewCal parameter isn't present, then calibration will be determined automatically (see "Calibration [bit/mm] – auto", page 12).
  (Example: NewCal = 950)
- Fitorder (optional):
  The Fitorder parameter limits the polynomial fit's order. Integers from 1 to 5 enable the polynomial fit and determine its degree. Integers greater than 5 get clipped to 5.
  If you specify Fitorder = 0 or don't supply this parameter, then correXion pro will automatically set the polynomial fit's order.
  (Example: Fitorder = 3)
- RTCInputInmm (optional):
  If control values (RTC-X and RTC-Y, see "Measurement Data", page 9) are specified in millimeters ([mm]) rather than bits, then you must supply the RTCInputInmm parameter.
  This parameter needs to appear somewhere before the measurement data. Hence, you can place other parameters between this parameter and the measurement data.

You must supply the parameter OldCTFile and – when you start correXion pro in silent mode (see chapter 4.6, page 18) – the parameter NewCTFile. Otherwise, no new correction file will be created. The other parameters are optional. The parameters Tolerance and NewCal can also be subsequently supplied or changed in correXion pro (dialog mode). If not supplied, they will be automatically set by correXion pro.

Directives

Limits (optional):
A directive instructing the correXion program to reduce the usable image field produced by the correction file to the smallest square that encompasses all test points.
If it's necessary to restrict the correction file on more complex areas, instead of Limits the directive Polylimits (see below) should be used in the data file.

Polylimits (optional):
A directive instructing the correXion program to reduce the usable image field produced by the correction file to the smallest convex polygon that encompasses all test points.

A value >0 (e.g. Limits = 5) enlarges the limits by the given value in percentages. If no value is set, this corresponds to Limits/Polylimits = 0.
(Also see "Restricted correction file", page 13).

Both directives (Limits und Polylimits) can be used together in the data file. Then, the last appearing directive is valid.

Measurement Data

For each marked grid point, the corresponding digital x and y control values to the RTC® (RTC®-x and RTC®-y, in [bit]) and the measured x and y values (actual-x and actual-y, in [mm]) must be entered as follows:
RTC®-x RTC®-y actual-x actual-y
(example: -11500 0 -23.5724 0.0376)

- Values should be separated with a space.
- Begin each test point with a new line.
- Both the decimal point and the decimal comma are acceptable as decimal separator characters.

4.4 How correXion Works

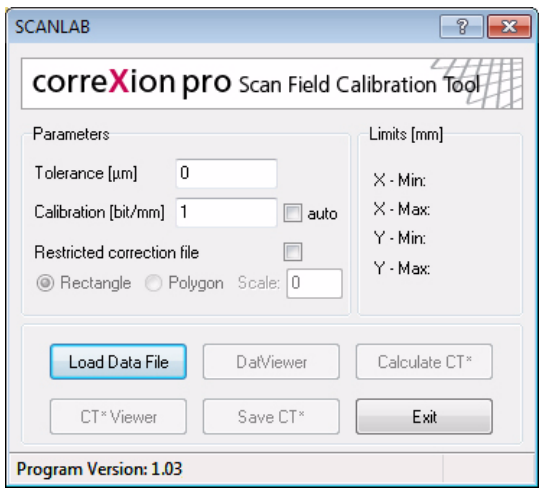
For each test point, the correXion program uses the original correction file and both digital values in the data file to produce a pair of values that the RTC® can output to the scan system. Then both the measured x coordinates and the y coordinates (in [mm]) of all test points are subjected to a two-dimensional fit receiving optimization until the desired tolerance is attained.

Inverses of the resulting fit functions are then used to calculate appropriate control values for any user-specified arbitrary point (x and y coordinates in [mm]) within the image field. correXion pro executes this calculation for the 65·65 or 257·257 image field grid points whose output values will be listed in the new correction file. The user can specify the distance between grid points within the image field by specifying a calibration factor. By using the command parameter “Limits” (in the data file) or “Restricted correction file” (with the correXion pro program in dialog mode), the user can restrict the image field area of the grid to that part occupied by the marked test points (also see “Restricted correction file”, page 13).

4.5 Using correXion pro in Dialog Mode

Step-by-Step Instructions

- If you haven't specified a path to the original correction file (that you used for marking the test points) (see "Parameters", page 8), then copy the file into the same directory as your data file. Otherwise the procedure will abort with the error message "File not found".
- For dialog mode, you start the program just like you would any other Windows program. The following dialog box then appears:



1

Graphical User Interface of the correXion pro program

Upon start-up, the dialog box's status bar displays the version number of the program.

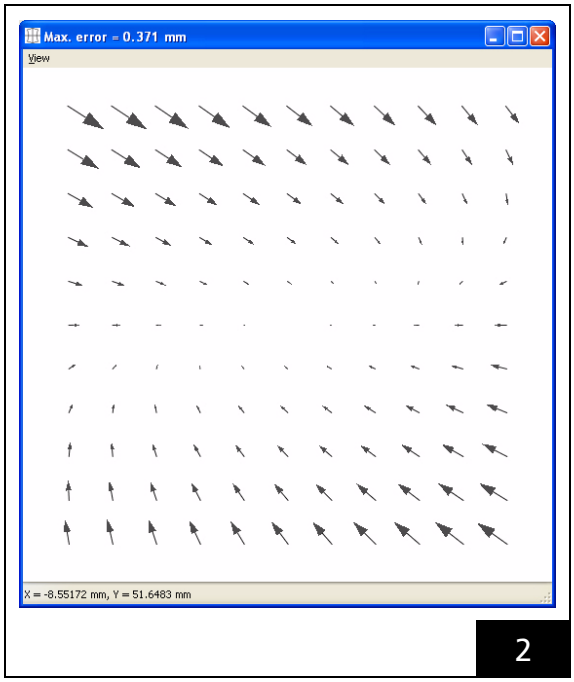
Note

Upon program start-up, some buttons display "CT*" (see figure 1).
After the data file loads, the display will change to "CT5" or "CTB" – depending on the entry for "OldCTFile" (see "Parameters", page 8).

- Click the {Load Data File} button to load the data file you created. A dialog box appears.
  If the program then detects a format error in one of the lines of your data file, it will display an appropriate error description: "CT5/CTB file size invalid".
  After an error-free data file has been loaded, the status bar displays the file name and the number of test points it contains.
- To graphically view deviations from the measurement points, click the {DatViewer} button. A new window will open:

Note

If the data file doesn't contain the parameter NewCal, then the {DatViewer} button will be disabled and graphical depiction won't be possible.



2

DatViewer - Vector field

The maximum error (in [mm]) is indicated in the title bar.

The “View” menu lets you choose between four different depictions:

– **Vector field** (see figure 2, page 11):
shows deviations from the regular grid (arrow lengths are normalized such that the longest arrow corresponds to the error indicated in the title bar).
– **Direction**:
shows the orientations of deviations (arrows always have the same length).
– **X-error**:
shows errors in the X direction (arrow lengths are normalized, see above).
– **Y-error**:
shows errors in the Y direction (arrow lengths are normalized, see above).
– **Show deviations from linear behavior**:
shows the deviations from linear behavior (arrow lengths are normalized, see above).

Move the cursor onto the depiction.
The status bar shows coordinates (in [mm]) of the point currently touched by the mouse pointer’s tip.

To continue the procedure, you must close the DatViewer by clicking the {X} symbol.

- Select the desired parameter setting (see "Parameter Settings", page 12).
- Start calculation of the new correction file by clicking the {Calculate CT*} button. A pop-up window will display the calculation’s progress.
- View the results in the “Limits” field and calculation feedback in the status bar. Click the {CT* Viewer} button if you want results displayed visually (see "Results and Feedback", page 13).
- If necessary, modify the parameters and click the {Calculate CT*} button again to start a new calculation.
- To save the new correction file, click the {Save CT*} button. In the same directory, a text file will also be generated containing all information shown in the selection window, as well as correXion pro’s version number and filenames of the data file, original correction file and new correction file.
- Close the program by clicking the {Exit} button.

Parameter Settings

- **Tolerance [μm]**:
This parameter determines the maximum allowable deviation (in [μm]) between the calculated interpolation values and the measured values of the test points.
  – Default value: 0
  – Maximum value: 1,000,000
- **Calibration [bit/mm]**:
Here, you can specify a calibration factor in [bit/mm] for the new correction file, e.g. the same value as the original correction file. The specified value will get rounded to an integer. Consider the following when choosing a value:
  – If the specified calibration factor exceeds the calibration factor K_a obtained via “Calibration [bit/mm] – auto”, then the image field’s side length controllable by the correction file will be smaller than allowed by the galvo scanners’ maximum angle.
  – In contrast, if the specified calibration factor is smaller than K_a, then some possible RTC® input values might cause the galvo scanners to reach their limit stops and thus the desired positions can’t be reached. After calculation with such parameter settings, the following will be displayed in the status bar: “Warning: Galvo limit reached!” (also see “2D Plots”, page 14).
  – Default value: 1
  – Maximum value: 100,000
- **Calibration [bit/mm] – auto**:
If the “auto” checkbox is enabled, then correXion pro will set the calibration factor K_a such that the 65·65 or 257·257 grid points of the new correction file cover the maximum possible image field.

With l_{max} as the maximum side length in [mm], the calibration factor is calculated in accordance with $K_a = 2^{16}/l_{max}$ or $K_a = 2^{20}/l_{max}$ (3) and rounded thusly:

- to an integer (a value divisible by 16 bit/mm (4)) if $K_a \leq 100$ bit/mm
- to a value divisible by 5 bit/mm (80 bit/mm (4)) if 100 bit/mm $< K_a \leq 1000$ bit/mm
- to a value divisible by 10 bit/mm (160 bit/mm (4)) if $K_a > 1000$ bit/mm

- **Restricted correction file**:
  The new correction file will be calculated so as to reduce the controllable image field to a minimum square or a minimum convex polygon just large enough to encompass all marked test points.
  - Select Rectangle or Polygon by enabling the corresponding radio button.
  - If you enter a value >0 in the "Scale" input field, the limits will increase by the specified amount (in percent) with respect to the rectangle's/polygon's mid-point.
  - If no calibration factor is specified via "Calibration [bit/mm]" (see above), then correXion pro calculates an initial calibration factor as per $K = 2^{16} / (2 \cdot s_{max})$ or $K = 2^{20} / (2 \cdot s_{max})$, whereby s_{max} represents the maximum absolute value of all test points.
    Because the calibration factors for both axis directions are identical, the grid points will cover a square surface having a side length of $2^{16} / K$ or $2^{20} / K$ (and with the specified measurement null point as the center). Therefore, a few grid points might sometimes lie outside the image field's minimum square area that just encompasses all marked test points. The new correction file assigns these points the same output values as the nearest points on the square's border.
  - If you enter a calibration factor at "Calibration [bit/mm]" (see above) that significantly exceeds the calibration factor derived via "Calibration [bit/mm] – auto", then the image field controllable by the correction file could sometimes be even smaller than the minimum square.
    In such cases, the warning "Image field reaches Galvo Limits" will be displayed.

(3) ctb correction files (for RTC®2-, RTC®3 and RTC®4 boards) use the equation $K_a = 2^{16}/l_{max}$ to calculate correction factors, whereas ct5 correction files (for RTC®5 boards) use $K_a = 2^{20}/l_{max}$.

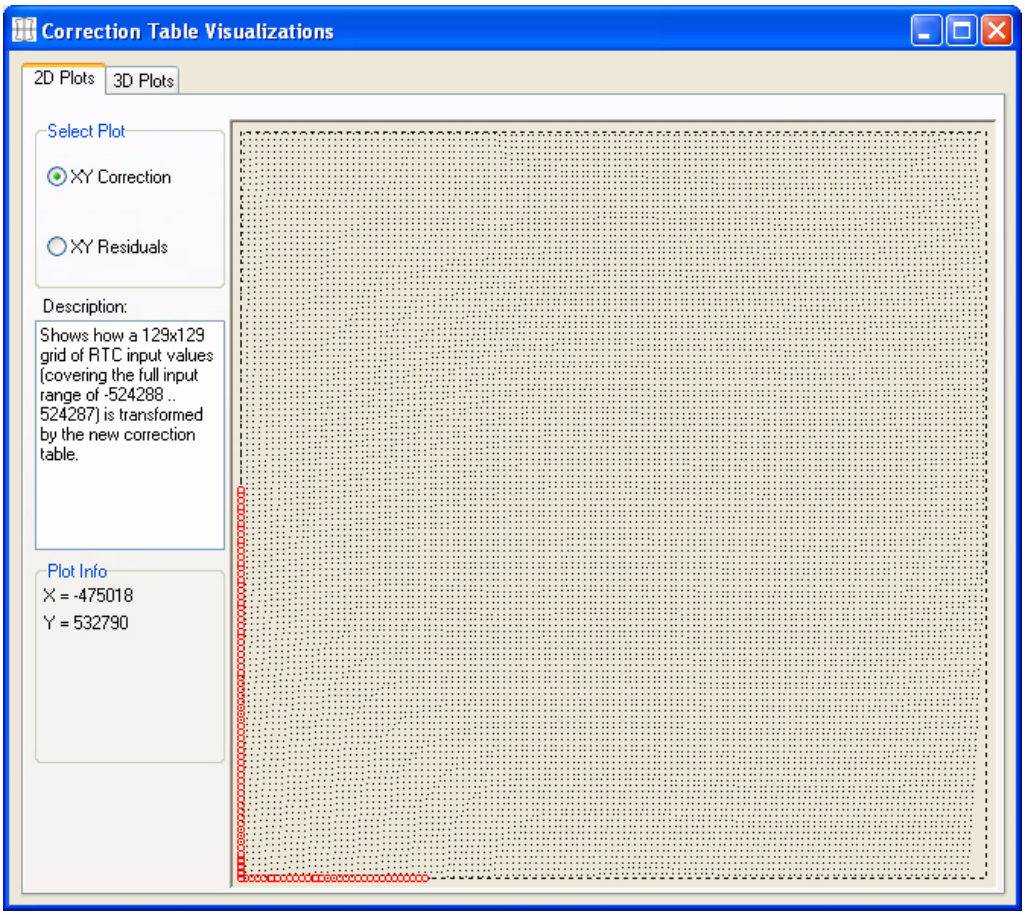
(4) Numbers in parentheses are applicable to ct5 files, the others are applicable to ctb files.

Results and Feedback

- **Accuracy of fit**:
  If the fit procedure concludes successfully, then the status bar will display the maximum error Δf ("Max. error at testpoints" or "Max. deviation at testpoints") in [µm]. The maximum error is calculated from the maximum cartesian deviation of the fit function from the measurement points.
- **Error messages**:
  If the procedure aborts or fails to start, the status bar will display an error message:
  - "No fit possible" implies that test point data was entered incorrectly.
  - "CT5/CTB file size invalid" indicates that the output correction file wasn't of the correct format.
  - "DataFile not found" indicates that the data file doesn't exist.
  - "Old correction file not found" indicates that the original correction file doesn't exist.

  (For further error messages, see the table on page 19.)
- **Limits** [mm]:
  This field displays the image field borders in [mm] set by the new correction file.

▸ To visualize results, click the {CT* Viewer} button. A "Correction Table Visualizations" window will open (see figure 3, page 14).



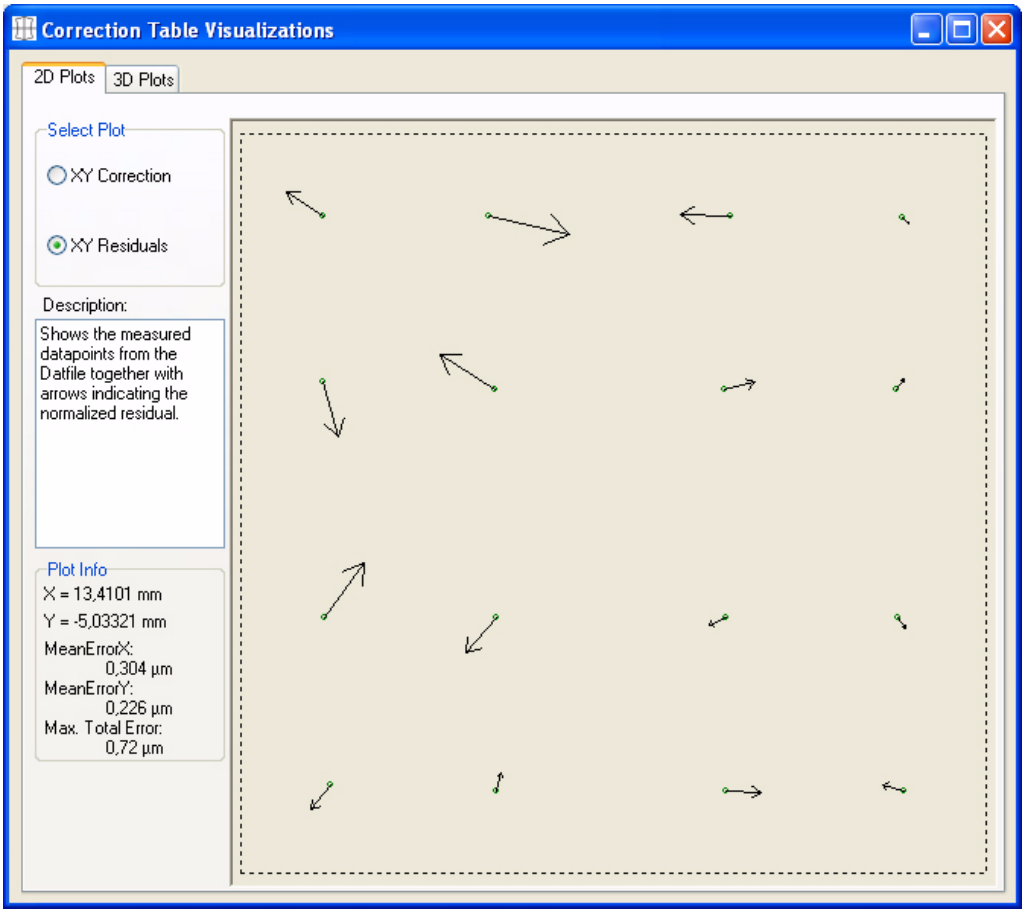
3

CT* Viewer\2D Plots – XY Correction

- **2D Plots**:
  The "2D Plots" tab is always displayed initially.
  As you move the cursor across the depiction, X and Y positions are shown in the "Plot Info" field.
  If you select "XY Correction" in the "Select Plot" field, then the output values (galvo control values) of the new correction file's 65·65 points (RTC®2/RTC®3/ RTC®4) or 129·129 points[5] (RTC®5) will be shown in a diagram. The points are typically distributed along curved lines. A dotted rectangular outline indicates the maximum possible control values.

  Grid points residing outside this area (whereby the galvos would reach their limits) are depicted as red circles (also see "Calibration [bit/mm]", page 12). In this case, you should increase the calibration factor somewhat before a new calculation.

(5) Though 129·129 grid points are depicted, the calculation is performed for 257·257 grid points.

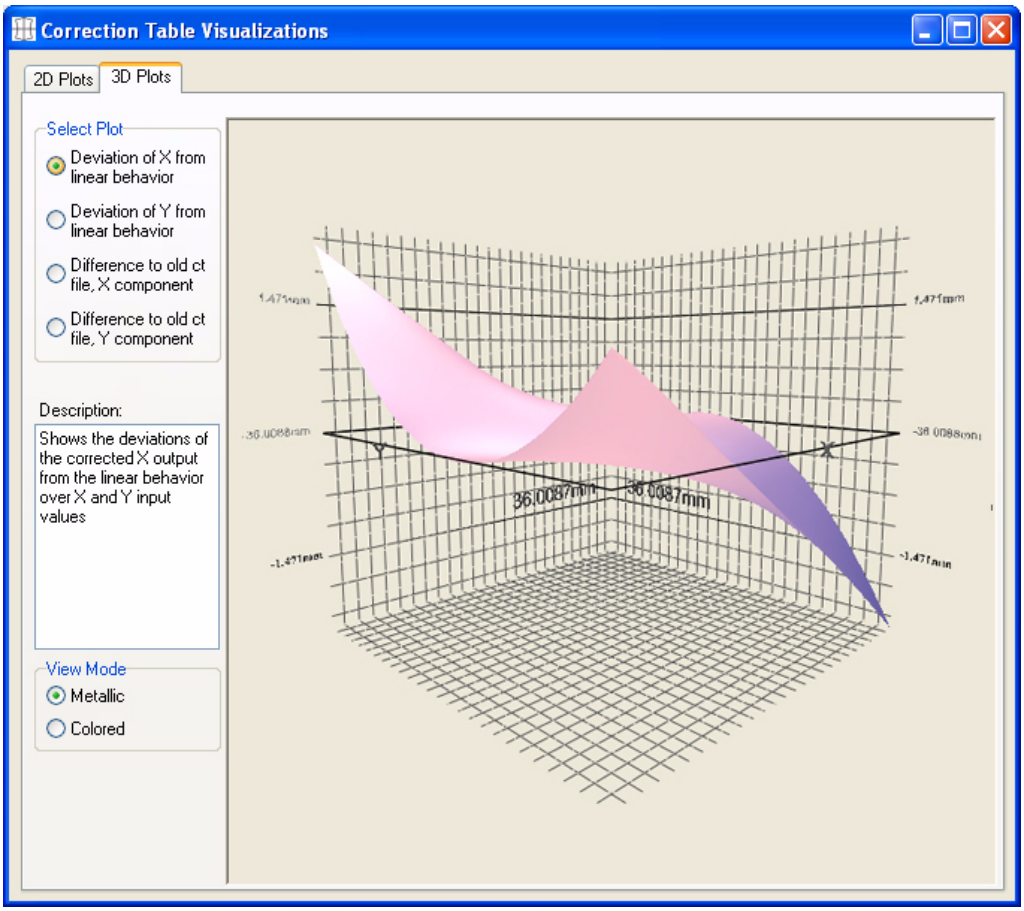


4

CT* Viewer\2D Plot – XY Residuals

If you select “XY Residuals” in the “Select Plot” field, then the theoretical residual error of the specified test points will be displayed. The arrows are normalized such that the longest arrow represents the maximum error (see figure 4).

The “Plot Info” field displays the mean error value (MeanErrorX/Y) and maximum error (Max. Total Error).



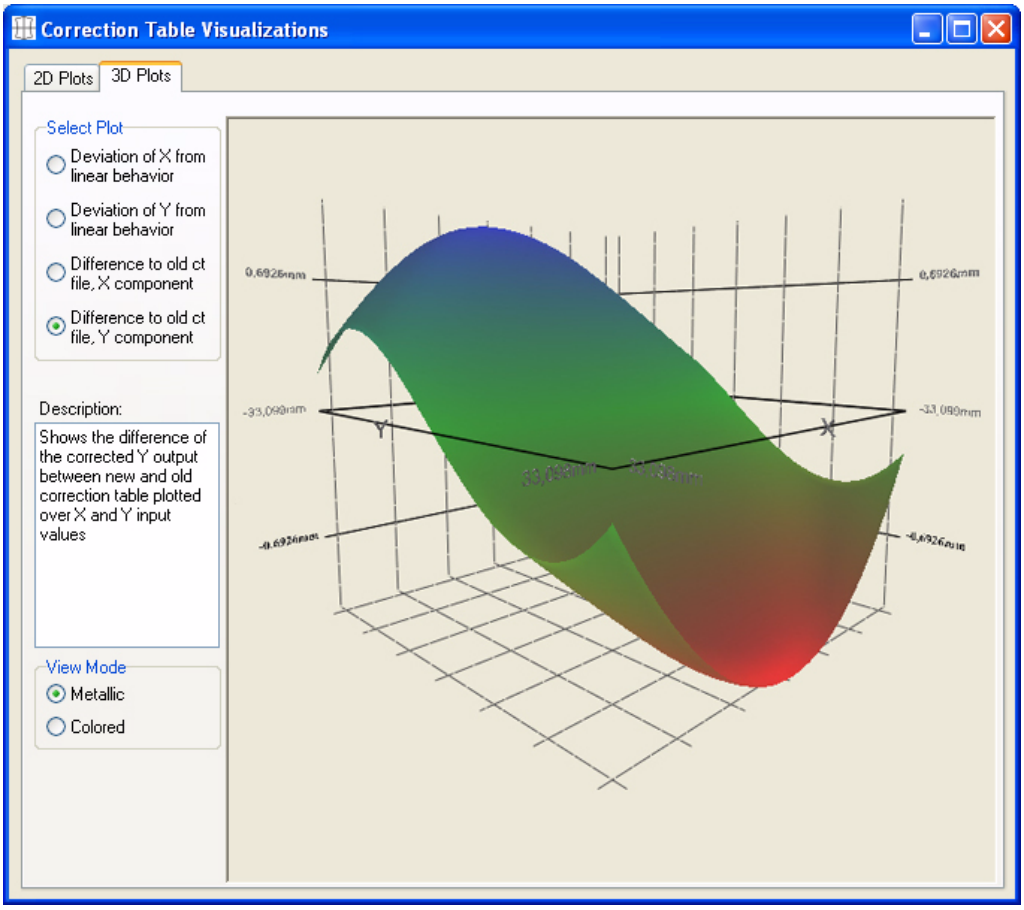
5

CT* Viewer\3D Plot – Deviation of X from linear behavior (Metallic view mode)

- **3D Plots**:
  The "3D Plots" tab lets you select among the following depictions:
  - **Deviation of X from linear behavior** (see figure 5):
    Shows how much the corrected X values deviate from linear behavior of the X and Y input values.
  - **Deviation of Y from linear behavior**:
    Shows how much the corrected Y values deviate from linear behavior of the X and Y input values.
  - **Difference to old ct file, X component**:
    Shows how much the original and new correction tables' corrected X values differ for X and Y-plotted input values.
  - **Difference to old ct file, Y component** (see figure 6, page 17):
    Shows how much the original and new correction tables' corrected Y values differ for X and Y-plotted input values.

  A bold outline depicts the values shown in the "Limits" field (see figure 1, page 11).

  The "View Mode" field lets you choose between **Metallic** (see figure 5) and **Colored** (see figure 6).



6

CT* Viewer\3D Plot – Difference to old ct file, Y component (Colored view mode)

Colored view mode depicts relatively large positive deviations as blue and relatively large negative deviations as red.

Return to the dialog box by closing the “Correction Table Visualizations” window via the {X} symbol.

4.6 Using correXion pro in Silent Mode

The correXion program can be started in silent mode under Windows via "Start/Run" or from another program by appending the name of the data file as a command line parameter:

correXion pro [*name of created data file*] [-s]

In silent mode, calculations are performed directly without an interactive dialog box. If the [-s] parameter is added to the command line, then calculation is performed completely in the background. Without the [-s] parameter, a progress indicator is shown during calculation.

All desired parameter settings and directives must be contained in the data file – otherwise, a new correction file won't be created.
Please note the following:

- The data file lets you specify the directory path of the output correction file (that you used for marking the test points). The output correction file must then reside in this directory; otherwise the program won't generate a new correction file.
- If no directory is specified, then the data file's directory will be automatically selected.
  Here, you need to copy the original correction file into the data file's directory before starting the program; otherwise the program won't generate a new correction file.
- If the "Tolerance" parameter isn't specified, then it will be automatically set to "0 μm".
- If the calibration factor "NewCal" isn't specified in the data file, then the calibration factor will be auto-selected similarly to dialog mode's "Calibration [bit/mm] – auto" (see page 12).
- If a name for OldCTFile (the original correction file) isn't specified, then the fit procedure won't start.
- If a name for NewCTFile (the new correction file) isn't specified, then a new correction file won't be created.
- If the path specified in NewCTFile doesn't exist, then a new correction file won't be generated.

If the data file contains all necessary contents and no error occurs, then a new correction file and a text file will be generated (similarly to dialog mode's {Save CT*}, see page 12). Both files will be written to the specified directory or the directory in which the data file is stored (see above).

It's often best to use the output correction file's calibration factor.

The calculation process returns 0 if no error occurred. If an error occurs, then a corresponding error code will be returned (for a description of error codes, see the table on page 19).

Error Code	Error Message "Error: ..."	Cause
10	Old correction file not found	Incorrect directory or data filename
11	Could not open old correction file	File access denied
12	CT5 file size invalid / CTB file size invalid	Invalid file format
14	Could not create new correction file	Directory doesn't exist or file system access denied
15	Saving CT5 file failed / Saving CTB file failed	Unable to save
16	DataFile not found	File missing
17	Open DataFile failed	File access denied
18	Old correction file command missing	OldCTFile command missing or incorrect
20	Invalid file extension	Incorrect file extension for original or new correction file
21	No fit possible	Fit failed, implies that test point data is possibly incorrect
23	Not enough memory	Insufficient system memory (try closing other programs)
26	AutoCalibration failed	Auto-calibration not possible, try manually specifying a calibration factor
27	computing new correction file failed	Indicates incorrect calibration or too few test points

4.7 Compatibility with correXion and correXion5

correXion pro is compatible with SCANLAB's correXion and correXion5 programs. Thus, correXion pro can load data files created with correXion andcorreXion5.

Here, correXion pro ignores the following captions – used by correXion and correXion5, but not by correXion pro:

correXion:

- [FITORDER]
- [FITORDER - auto]

correXion5:

- [RTC4]
- [FITORDER]
- [SMOOTHING]
- [AUTO_FIT]
- [LIMIT(bit)]
- [LIMIT(MM)]
- [OFFSETX]
- [OFFSETY]
- [DEVIATION]
- [APPLY_OFFSET]

Note

If you load a data file created with correXion5, then correXion pro will interpret values for [TOLERANCE] as mm values (as does correXion5).

Notes