AN002: Calibrated lenses data files

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1. Calibration data file download

Calibrated lenses have data files linked to each lens individually whereas Theia's -IQ lenses use a common data file that is updated periodically to reflect the current variations in production. The data files can be accessed via Theia's web database and are linked to the lens by serial number.

Calibrated lenses will come with a QR code to link to the online data. No login credentials are required and the data can be downloaded multiple times.

2. Calibration data file interpretation

Data files can be read by any text editor. They are formatted with a JSON structure for reading by an automated program. The top level data includes information about the lens and each calibration type has a sub-section which can contain multiple curves for different calibration points.

2.1. Lens header information

The top of the file will have information about the lens. Not all keys will be included depending on the calibration test suites that were completed for the lens. Listed below are all the keys for the header information.

```
{   "manufName": "Theia Technologies",
    "sn":"TW50P-A00001",
    "name":"TL410P R6",
    "fam":"TW50",
    "flMin":4.15,
    "flMax":9.9,
    "fnum":1.4,
    "zoomSteps":4073,
    "zoomPI":154,
    "focusSteps":9353,
    "focusPI":8654,
    "irisSteps":75,
    "ffl":12.5,                     flange focal length
    "ihmax": 9.4,                   maximum sensor diagonal
    "odmin": 1.0,                   minimum focusable object distance
```

```
"datafile":"2023-01-19",            lens data file update date
"planfile":"2023-02-11",            test plan file update date
"jsonRev":"2023-03-08",             JSON format revision (this file)
"ts":"2022-02-27T10:28:28-08:00"    calibration time in ISO 8601 format
"BLFocus":20,                       measured backlash focus motor
"BLZoom":10,                        measured backlash zoom motor
"cutOn":440.3,                      blue filter 50% cut-on wavelength
```

2.2. Calibration data

Calibration data is stored as coefficients for up to 10th order polynomial.

$$y = \sum_{k=0}^{10} P_k * x^k$$

There may be multiple curves for each calibration type depending on up to 2 control points. For example, lens distortion is stored as polynomial coefficients for the object angle (y-axis) vs. image height (x-axis). Distortion is also a function of lens focal length and object distance control points (although in the data shown below there is no variation for the object distance control point). There may also be polynomial coefficients for an inverse calculation x = f(y) provided for convenience. Theia has other application notes that go into more detail about the curve fitting for different calibration types.

Each calibration type will be listed at the same JSON level as the lens data. Calibration types are:

Name	Function	Y axis	X axis	Control point 1	Control point 2	Inv. Avail.
tracking	Focus/zoom tracking	Focus motor step	Zoom motor step	Object distance (1000/obj dist [m])	--	
dist	Distortion	Object angle [deg]	Image height [mm]	Focal length [mm]	Object distance (1000/obj dist [m])	✓
FL	Focal length conversion	Zoom motor step	Focal length [mm]	Object distance (1000/obj dist [m])	--	✓
RI	Relative illumination	Illumination [%]	Image height [mm]	Focal length [mm]	Aperture [1/(2*F/#)]	
AP	Aperture	Aperture [1/(2*F/#)]	Iris motor step	Focal length [mm]	--	✓
iris	Iris diameter	Iris short diameter	Iris motor step	Focal length [mm]	--	

For example, the distortion calibration type shown below has 3 curves for different focal lengths. It will be stored in the data file in the following format. The control points and polynomial curve coefficients are stored in separate arrays where cp1[n], cp2[n], and coef[n][0~10] all correspond to the nth calibration curve.

```
{
  …,
  "dist": {                               Calibration name
    "type": "cal",                        Family design data "des" or
                                          individual lens calibrated data "cal"
    "idx": 2,                             Calibration index number
    "count": 3,                           Number of calibrated curves
    "xAxis": "image ht [mm]",             Label
    "yAxis": "ang [deg]",                 Label
    "cp1Type": "FL",                      Control point label
    "cp2Type": "1000/obj dist",           Control point label
    "cp1": [                              List of control point 1 values (FL)
      12.38,
      24.61,
      50.09
    ],
```

```
    "cp2": [                           List of control point 2 values (1000/OD)
      0.001,
      0.001,
      0.001
    ],
    "coef": [                          10th order polynomial coefficients
      [
        4.550697E-03,                  P0 (constant)
        -4.624167E+00,                 P1 (linear)
        -1.172306E-02,                 P2 (quadradic)
        1.208410E-03,                  P3 (cubic)
        -2.458095E-03,                 P4
        ...,                           Additional coefficients up to P10
      ],
      [
        2.340296E-03,
        -2.330146E+00,
        1.940843E-03,
        7.774922E-05,
        -2.478764E-04
      ],
      [
        1.153122E-03,
        -1.146048E+00,
        2.996189E-03,
        6.989418E-04,
        5.265576E-05
      ]
    ]
  },
  …
```

3. Software

Theia provides software modules to allow reading and using the calibrated data easier. There are 2 Python modules and a graphical user interface (GUI) for each module available. The TheiaMCR module formats the commands to be sent to the motor control board. The Theia Lens IQ software converts from engineering units (meters, degrees) to motor steps. Both these module increase the ease of use of Theia's motorized lenses.

3.1. TheiaMCR motor control module

The Python module TheiaMCR is used to format the commands to be sent to the motor controller. These commands have a specific byte string format. The TheiaMCR module does the formatting so that the user only needs to enter motor steps. There is a GUI that can be used on top of this module for user interaction. Find more information in Theia's motor control setup guide and webpage[1]. This software is available with an open-source BSD license[2] so the module can be integrated into the customer's software.

[1] Theia motor control webpage and links to setup guide and GUI application (https://www.theiatech.com/lenses/accessories/mcr/)
[2] TheiaMCR license https://bit.ly/THEIABSD

The functions that the TheiaMCR module has are:

Function	Description
initFocus	Initialize the focus motor with step range, speed, and limits.
initZoom	Initialize the zoom motor with step range, speed, and limits
initIris	Initialize the iris motor with step range and speed
initIRC	Initialize the IR cut switch
Motor movement functions	
focusRel	Move the focus motor a relative number of steps
focusAbs	Move the focus motor to the home position and then to the final step position
zoomRel	Move the zoom motor a relative number of steps
zoomAbs	Move the zoom motor to the home position and then to the final step position
irisRel	Move the iris motor a relative number of steps
irisAbs	Move the iris motor to the home position and then to the final step position

3.2. Theia Lens IQ™ ease of use module

The Theia lens IQ™ Python module allows the user to input values in understandable engineering units such as focal length in millimeters or field of view in degrees or meters. The functions in the class calculate motor positions based on the default design data (for Theia -IQ lenses) or individual lens calibrated data. The calculation can also be reversed to get engineering units from motor step positions. This software is available with an additional license fee. Contact Theia for more information.

Some of the functions are shown in the table below.

Function	Description
Functions to calculate engineering units from motor step positions	
zoomStep2FL	Calculate the focal length from zoom motor step position
focusStep2OD	Calculate the object distance at a focal length for a given focus motor step position
irisStep2NA	Calculate the numeric aperture from iris motor step position. Numeric aperture is used in field of view calculations.
irisStep2FNum	Calculate the F/# from iris motor step position.
Functions to calculate motor step positions from engineering units	
FL2ZoomStep	Calculate the zoom motor step position for a given focal length
ODFL2FocusStep	Calculate the focus motor step position for a given focal length and object distance
NA2IrisStep	Calculate the iris motor step position for a given numeric aperture
fNum2IrisStep	Calculate the iris motor step position for a given F/#
AOV2MotorSteps	Calculate the zoom and focus motor step positions for a given angle of view in degrees
FOV2MotorSteps	Calculate the zoom and focus motor step positions for a given field of view in distance units and object distance.
Complex calculation functions	
calcAOV	Calculate the angle of view in degrees for a given focal length
calcFOV	Calculate the field of view in distance units for a given focal length and object distance
calcDOF	Calculate the depth of field and the minimum and maximum object distances that are in focus

5. Revisions

Version	Change	Reason
220408		Preliminary release
221209	Added iris calibration curve	Used for calculating depth of field
230728	Removed visualizer program	Moved to AN005
	Added software library information	
240119	Changed software names, adjusted license information	Official release of software