ASU TTCAM Calibrated Data Product Pipeline User's Guide
Ver. 1.6, last edited 2 July 2024

Getting Started

The CDP pipeline makes use of the [IDL Astronomy User's Library](#), which uses parts of the [IDL Coyote Graphics Library](#). Before running the pipeline, the IDLASTRO and Coyote libraries must be installed and on the IDL search path. See [quick tips for customizing your IDL program search path](#) for information on setting the IDL search path.

Code Repository

The main script is an IDL procedure called `ttcam_calib.pro`. The helper functions are also in an IDL procedure called `ttcam_fnlib.pro`. The `MASTERCALIB` directory holds the additional calibration files (bad pixel map, flat field, parameter file).

Running the Code

This assumes the user is on jojo and in the TTCAM_CDP directory as described above. To run the code as it is on jojo, start IDL in the TTCAM_CDP directory.

Set the search path to include the IDLASTRO and Coyote libraries:

```
IDL> PREF_SET, 'IDL_PATH', '<IDL_DEFAULT>:+/usr/local/idl/', /COMMIT
```

If this does not work, type the command (bash shell):
```
% export IDL_PATH="<IDL_DEFAULT>:+/IDL"
```
Or the following for csh:
```
% setenv IDL_PATH "<IDL_DEFAULT>:+/IDL"
```

Then compile and run the main procedure using the test files given in the TTCAM_CDP directory:

```
IDL> .compile ttcam_fnlib
IDL> .compile ttcam_calib
IDL> ttcam_calib, 'testinput.csv', 'testoutput.csv', 'testlog.txt'
```

The sample input, `testinput.csv`, is described below and also given in Appendix A. The sample outputs, including `testoutput.csv`, `testlog.txt`, and the CDP are also described below and examples given in the Appendix.

Function Library

The main procedure depends on a library of helper functions, defined in ttcam_fnlib.pro. Below is a list of those functions and their intended purposes.

FUNCTION TTCAM_MEDPIX, *IMG, I*

> Find the median of the surrounding pixels.
> **Input:**
>> *IMG* - 2d image array of any size
>> *I* - index of center pixel to be replaced
>
> **Output:** 2-value vector with [0] median value, and [2] error on median

FUNCTION TTCAM_TIMEFORMAT

> Reformat timestamp() to use in log
> **Input:** none
> **Output:** String in the format YYYY-DOY-HH:MM:SS

FUNCTION TTCAM_READROW, *FILE*

> Read a file by row into an array of strings.
> (from https://www.harrisgeospatial.com/docs/READ.html)
> **Input:** Filename
> **Output:** Array of strings, where each row is an array element.

FUNCTION TTCAM_SCALETO16, *DATA, BZERO, BSCALE*

> Scale a data array with 32-bit IEEE single precision floats into 16-bit signed integers.
> **Input:**
>> *DATA* - array with 32-bit FLOAT
>> *BZERO* - variable name for bzero
>> *BSCALE* - variable name for bscale
>
> **Output:** Data array with 16-bit INT

Main Procedure

PRO TTCAM_CALIB, *INPUTFILE, OUTPUTFILE, LOGFILE, SHUTTERSMEAR=shuttersmear, NOIOF=noiof, NOSCALE=noscale, SILENT=silent*

Main script for Lucy TTCam calibration pipeline.

Input:
INPUTFILE (string) - filepath + name of a .csv input spec file with
> [0] Instrument
> [1] UDP_path+filename

[2] CDP_path+filename
[3] cal_file_directory (more under "Additional Calibration Files" below)
OUTPUTFILE (string) - filepath + name of a .csv output spec file
LOGFILE (string) - filepath + name of .txt log file
/SHUTTERSMEAR (optional) - if set, implements shutter smear correction
/NOIOF (optional) - if set, does not implement I/F conversion
/NOSCALE (optional) - if set, does not scale output calibrated FITS to 16-bit integer for storage
/SILENT (optional) - if set, suppresses log output to terminal

Output:
.csv output spec file with
[0] Instrument
[1] CDP_path+filename
[2] Status flag, where
0 = nominal execution and creation of the CDP data file
1 = an error occurred, but a CDP data file still was created
2 = an error occurred, and no CDP data file was created
.txt log file with format <timestamp> <level> <text>, where
<timestamp> is in the format YYYY-DOY-HH:MM:SS.
<level> is that line's type of information (INFO, REPORT, WARNING, or ERROR)
<text> is free-format details of the given log event.
(more under "Log File" below)
Calibrated FITS file
Main image: Radiance (uW/cm^2/sr)
Extension 1: Bad pixel map, where 0=good pixel, 1=bad pixel, 2=saturated pixel, 3=nonlinear
pixel; 4=zero-clipped pixel (sqrt compand)
Extension 2: Radiance error (uW/cm^2/sr)
Extension 3 (if /IOF keyword is set): I/F (unitless)
Extension 4 (if /IOF keyword is set): I/F error (unitless)

Additional Calibration Files:
The script also reads in a parameter .txt file for each camera, which gives information about the properties
of the camera for calibration. The parameter file should be a .txt file with six lines, where the first four
lines consist of a few numbers separated by spaces and the last two are filenames in the following order:
[0] dark model parameters $C1+C2*exp(C3*T)$ in form C1 (no bias), C1err (no bias), C1 (with
bias), C1err (with bias), C2, C2err, C3, C3err
[1] radiance conversion coefficient and error [(μW/cm^2/sr)/(DN/msec)]
[2] nonlinear DN value and saturated/full well DN value [DN]
[3] scale factor and error [e-/DN]
[4] bad pixel map filename
[5] flat field filename
The parameter file, bad pixel map, and flat field should all be in the same cal_file_directory given by the
INPUTFILE.

Log File:
The log file is a text file that logs all attempts, successes, and failures for each CDP, as well as warnings or errors for each. INFO and REPORT lines are self-explanatory. WARNING lines are non-critical. Possible WARNING lines are:

1. Invalid T2CCHTMP, DVRON, T2CAI013, or SPCTSORN values from the UDP header. See Assumptions & Notes section.
2. If there is a non-critical math error (type conversion errors, math errors) this usually means that while there is a problem with calibration, the CDP has still been built. The log file will print the latest math error to aid in debugging.

ERROR lines mean that there is a critical error that is preventing the UDP from being calibrated. An ERROR line is followed by a REPORT of a failed calibration before the code attempts to calibrate the next UDP. Possible ERROR lines are "Input is not decompanded." or "Input size is disallowed; only images of size 2752x2004 or 2592x1944 can be calibrated." Note that the ERROR line is not always descriptive of the actual error in the code. It acts as a flag for critical errors and an aid in debugging.

Assumptions & Notes

1. The pipeline assumes two possible sizes of the UDP: 2752x2004 (with overscan) or 2592x1944 (without overscan). Any UDPs with other sizes will not be calibrated and an ERROR will print to the log.
2. **(New in ver 1.4)** There is only one accepted T2CAI013 (gain) value taken from the UDP header:
   8 (corresponds to gain = 1)
   If the T2CAI013 value does not match this, then an ERROR will print to the log and calibration will not proceed.
3. If there is no temperature given by the UDP header and there is no overscan, then a WARNING will print to the log and the dark correction will be done with an assumed temperature of -20C.
4. The DVRON value from the UDP header should be equal to either 0 for camera SN194503, or 1 for camera SN194504. If the DVRON value is invalid, then a WARNING will print to the log and an assumed value of 0 will be used.

Appendix A: Example input.csv file

```
Instrument,UDP_path+filename,CDP_path+filename,calib_file_directory
TTCam,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/UDP/t194503cyn006_1.FIT
,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/t194503cyn006_1_cal.FIT,
/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/MASTERCALIB/
TTCam,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/UDP/t194503cyn006_2.FIT
,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/t194503cyn006_2_cal.FIT,
/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/MASTERCALIB/
TTCam,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/UDP/t194503cyn006_5.FIT
,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/t194503cyn006_5_cal.FIT,
/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/MASTERCALIB/
```

```
TTCam,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/UDP/ttc_0123456789_eng_
1.fit,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/ttc_0123456789_eng_
1_cal.fit,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/MASTERCALIB/
```

Appendix B: Example output.csv file

```
Instrument,CDP_path+filename,Flag
TTCam,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/t194503cyn006_1_cal
.FIT,1
TTCam,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/t194503cyn006_2_cal
.FIT,0
TTCam,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/t194503cyn006_5_cal
.FIT,0
TTCam,/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/ttc_0123456789_eng_
1_cal.fit,1
```

Appendix C: Example log.txt file

```
2020-346-23:23:44 INFO ---------------------------------
2020-346-23:23:44 INFO Start of LUCY TTCAM CDP processing
2020-346-23:23:44 INFO ASU Version 1.0
2020-346-23:23:44 INFO ---------------------------------
2020-346-23:23:44 INFO ---------------------------------
2020-346-23:23:44 REPORT Attempting to calibrate
/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/UDP/t194503cyn006_1.FIT
2020-346-23:23:44 WARNING Invalid T2CAI013 (gain) value; default T2CAI013 = 8
(gain = 1) used.
2020-346-23:23:47 REPORT Successfully calibrated
/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/t194503cyn006_1_cal.FIT
2020-346-23:23:47 INFO ---------------------------------
2020-346-23:23:47 REPORT Attempting to calibrate
/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/UDP/t194503cyn006_2.FIT
2020-346-23:23:50 REPORT Successfully calibrated
/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/t194503cyn006_2_cal.FIT
2020-346-23:23:50 INFO ---------------------------------
2020-346-23:23:50 REPORT Attempting to calibrate
/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/UDP/t194503cyn006_5.FIT
2020-346-23:23:52 REPORT Successfully calibrated
/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/t194503cyn006_5_cal.FIT
2020-346-23:23:52 INFO ---------------------------------
2020-346-23:23:52 REPORT Attempting to calibrate
/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/UDP/ttc_0123456789_eng_1.fit
2020-346-23:23:52 WARNING Invalid T2CCHTMP value; default T2CCHTMP = -20C
used.
2020-346-23:23:53 WARNING Invalid T2CAI013 (gain) value; default T2CAI013 = 8
(gain = 1) used.
```

```
2020-346-23:23:55 REPORT Successfully calibrated
/mnt/lucy/soc/instruments/stage/ttcam/TTCAM_CDP/CDP/ttc_0123456789_eng_1_cal.
fit
2020-346-23:23:55 INFO --------------------------------
2020-346-23:23:55 INFO --------------------------------
2020-346-23:23:55 INFO End of LUCY TTCAM CDP processing
2020-346-23:23:55 INFO --------------------------------
```

Appendix D: Calibrated Data Product Header (Added Keywords ONLY)

D.1 Main Image: Radiance

Keyword	Value (Type and Permissible Values)	Comment
HISTORY	******	
CDPVER	1.0	CDP TTCam code version
UNITS	uW/cm^2/sr	
UDPFILE		UDP filename used for CDP
FLATFILE		Flatfield filename
BPMFILE		Initial bad pixel map filename
PARAFILE		Parameter .txt filename
C1		Dark model parameter C1
C1_ERR		Error on C1
C2		Dark model parameter C2
C2_ERR		Error on C2
C3		Dark model parameter C3

Keyword	Value	Comment
C3_ERR		Error on C3
RADCOEF		Coefficient of conversion to radiance
RC_ERR		Error on radiance conversion coefficient
NONLIN		DN value above which pixels become nonlinear
BIAS		DN value subtracted for bias and dark cal
SCALEF		Scale factor (e-/DN)
HISTORY	******	
END		

D.2 Extension 1: Bad Pixel Map

Keyword	Value (Type and Permissible Values)	Comment
XTENSION	IMAGE	IMAGE extension
BITPIX	8	Pixel bit depth
NAXIS	2	Number of axis in the data array (2)
NAXIS1		Number of rows (lines)
NAXIS2		Number of columns (samples)
PCOUNT		No Group Parameters
GCOUNT		One Data Group
BSCALE		Multiplicative factor for scaled data

BZERO		Additive factor for scale data
HISTORY	******	
NBAD_1		No. of bad pixels flagged before launch
NBAD_2		No. saturated pixels
NBAD_3		No. nonlinear pixels (incl. sat pix)
NBAD_4		No. zero-clipped pixels
NONLIN	4080	DN value above which pixels become nonlinear.
HISTORY	******	
END		

D.3 Extension 2: Radiance Error

Keyword	Value (Type and Permissible Values)	Comment
XTENSION	IMAGE	IMAGE extension
BITPIX	8	Pixel bit depth
NAXIS	2	Number of axis in the data array (2)
NAXIS1		Number of rows (lines)
NAXIS2		Number of columns (samples)
PCOUNT		No Group Parameters
GCOUNT		One Data Group

Keyword	Value	Comment
BSCALE		Multiplicative factor for scaled data
BZERO		Additive factor for scale data
HISTORY	******	
UNITS	uW/cm^2/sr	
HISTORY	******	
END		

D.4 Extension 3: I/F

Keyword	Value (Type and Permissible Values)	Comment
XTENSION	IMAGE	IMAGE extension
BITPIX	8	Pixel bit depth
NAXIS	2	Number of axis in the data array (2)
NAXIS1		Number of rows (lines)
NAXIS2		Number of columns (samples)
PCOUNT		No Group Parameters
GCOUNT		One Data Group
BSCALE		Multiplicative factor for scaled data
BZERO		Additive factor for scale data
HISTORY	******	

Keyword	Value	Comment
UNITS	unitless	I/F or radiance factor is unitless
FSUN		TTCam solar radiance (uW/cm^2/sr) at 1 AU
TARG_AU		target heliocentric distance, in AU
HISTORY	******	
END		

D.5 Extension 4: I/F Error

Keyword	Value (Type and Permissible Values)	Comment
XTENSION	IMAGE	IMAGE extension
BITPIX	8	Pixel bit depth
NAXIS	2	Number of axis in the data array (2)
NAXIS1		Number of rows (lines)
NAXIS2		Number of columns (samples)
PCOUNT		No Group Parameters
GCOUNT		One Data Group
BSCALE		Multiplicative factor for scaled data
BZERO		Additive factor for scale data
HISTORY	******	
UNITS	unitless	I/F or radiance factor is unitless

HISTORY	******	
END		

References