An Overview of the IRAF DTOI Package

Suzanne Hammond Jacoby

IRAF Group - Central Computer Services
National Optical Astronomy Observatories*
February 1987
Revised July 1988

ABSTRACT

This document describes the DTOI package, which contains tasks for determining and applying a density to intensity transformation to photographic data. The transformation is determined from a set of calibration spots with known relative intensities. A curve is interactively fit to the densities and intensities of the calibration spots. The transformation is then applied and a new output image written.

*Operated by the Association of Universities for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.

Table of Contents

An Overview of the IRAF DTOI Package

Suzanne Hammond Jacoby

IRAF Group - Central Computer Services
National Optical Astronomy Observatories*
February 1987
Revised July 1988

1. Introduction

The DTOI package contains tasks for computing and applying a density to intensity transformation to photographic data. These tasks perform the standard steps in linearizing data: calculating HD data points from calibration spots, fitting a curve to these points and applying the HD curve to the data. It is also possible to combine related HD curves. Communication between the tasks is via text files which the user can inspect or modify. It is intended to be easy for users to introduce data from outside the DTOI package into the processing.

There are currently six tasks in the package. They are:

The **DTOI** Package

spotlist - Calculate densities and weights of calibration spots.
dematch - Match densities to log exposure values.
hdfit - Fit characteristic curve to density, exposure data.
hdtoi - Apply HD transformation to image data.
hdshift - Align related characteristic curves.
selftest - Test transformation algorithm.

The DTOI package does not currently support the self calibration of images, but the addition of this capability is planned. This would involve determining the HD curve from the data itself, by assuming the point spread function scales linearly with intensity.

Upon entering the package, your calibration spots and images to be transformed should be on the disk in IRAF image format.

2. Determining the HD Curve Data

To determine the HD curve, you need two sets of data: the measured photographic densities of a set of calibration spots and the log exposure values corresponding to these measurements. The log exposure values must be known a priori. Tasks *spotlist* and *dematch* are used to assemble these two data sets.

2.1. SPOTLIST

The first step is to calculate the density of the calibration spots, each of which is a separate IRAF image or image section. The spot density is either the median of the spot pixels or the mean of the pixels when pixels more then a user specified number of standard deviations away from the mean have been rejected. The numbers in the spot image must be scaled to density; parameter **spotlist.scale** is used such that density = input_value * scale. Task *spotlist* also calculates the standard deviation of each spot and reports the number of good pixels, i.e., the

*Operated by the Association of Universities for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.

number of pixels not rejected when determining the mean density. The final product of this task is a record in the data base containing a density for each spot. The scale factor used is also written to the data base; it will be read later in task *hdtoi*.

2.2. DEMATCH

Log exposure values must be matched to the measured density values. These log exposure values must be known a priori and will be read from a file. Task *dematch* retrieves the proper exposure information by matching the wedge number, emulsion type and filter used. Once a match has been made, the proper log exposure values are written to a record in the database.

A database of log exposure values for the NOAO standard wedges is maintained in a system file; the wedge/emulsion/filter combinations available are listed in last section of this document. This file can be replaced with one specific to any institution; the file name is supplied to task *dematch* as a parameter. In this way the wedge file can be personalized to any application and not be lost when the system is updated.

3. Fitting the Curve

The HD curve, or characteristic curve, is a plot of density versus log exposure. This curve is determined from the data points generated by tasks *spotlist* and *dematch*. The objective is to fit a curve to these points, such that Log exposure = F(Density). The technique available in this package allows the independent variable of the fit to be a transformation of the density (log opacitance, for example). The log exposure and density values are read from the database. If multiple entries for a particular record are present in the database, the last one is used.

3.1. HDFIT

Task *hdfit* fits a characteristic curve to density and log exposure values in preparation for transforming an image from density to intensity. Five functional forms of the curve are available:

Power Series
Linear Spline
Cubic Spline
Legendre Polynomials
Chebyshev Polynomials

It is possible to apply a transformation to the independent variable (density above fog) prior to the fit. The traditional choice is to fit log exposure as a function of the log opacitance, rather than density directly. This is sometimes referred to as the Baker, or Seidel, function. Transforming the density has the effect of stretching the low density data points, which tend to be relatively oversampled. In the DTOI package, four independendent variables are currently available:

Density
Log Opacitance
K50 - (Kaiser* Transform with alpha = 0.50)
K75 - (Kaiser* Transform with alpha = 0.75)

Any combination of transformation type and fitting function can be used and changed interactively. Two combinations of interest are discussed here.

---

* Margoshes and Rasberry, Spectrochimica Acta, Vol 24B, p497, (1969)

The default fit is a power series fit where the independent variable is Log Opacitance. That is:

$$Log\ Exposure = \sum_{k=0}^{ncoeff-1} A_k Y^k$$

$$where\ Y = Log\ Opacitance = Log_{10}(10^{Density} - 1)$$

A fit that is expected to best model a IIIA-J emulsion is a power series fit to a K75 transform of the density. That is,

$$Log\ Exposure = \sum_{k=0}^{ncoeff-1} A_k Y^k$$

$$where\ Y = K75\ transform = Density + 0.75\ Log_{10}(1 - 10^{-Density})$$

Over the expected small dynamic range in variables of the fit, legendre and chebyshev functions offer no advantages over a simple power series functional form. The cubic and linear spline fits may follow the data very closely, but with typically sparse data sets this is not desirable. It is expected that power series fit will serve satisfactorily in all cases.

3.1.1. Interactive Curve Fitting

Task *hdfit* can be run interactively or not. In interactive mode, points in the sample can be edited, added or deleted. Weighting values can be changed as well as the fog value, the type of transformation and the fitting function chosen. To obtain the best fit possible, interactive fitting is recommended. A complete list of the available commands is printed here; this list is also available interactively with the keystroke '`?`'.

```
                    DTOI INTERACTIVE CURVE FITTING OPTIONS

        ?           Print options
        a           Add the point at the cursor position to the sample
        c           Print the coordinates and fit of point nearest the cursor
        d           Delete data point nearest the cursor
        f           Fit the data and redraw or overplot
        g           Redefine graph keys.  Any of the following data
                    types may be along either axis:
                    x  Independent variable     y  Dependent variable
                    f  Fitted value             r  Residual (y - f)
                    d  Ratio (y / f)            n  Nonlinear part of y
                    u  Density above fog

Graph keys:

        h           h = (x,y)  transformed density vs. log exposure
        i           i = (y,x)  log exposure vs. transformed density
        j           j = (x,r)  transformed density vs. residuals
        k           k = (x,d)  transformed density vs. the y(data)/y(fit) ratio
        l           l = (y,u)  log exposure vs. density above fog (HD Curve)

        o           Overplot the next graph
```

`q`	Terminate the interactive curve fitting, updating the database file.
`r`	Redraw graph
`u`	Undelete the deleted point nearest the cursor
`w`	Set the graph window. For help type 'w' followed by '?'.
`x`	Change the x value of the point nearest the cursor
`y`	Change the y value of the point nearest the cursor
`z`	Change the weight of the point nearest the cursor

The parameters are listed or set with the following commands which may be abbreviated. To list the value of a parameter type the command alone.

`:show` [*file*]	Show the values of all the parameters
`:vshow` [*file*]	Show the values of all the parameters verbosely
`:errors` [*file*]	Print the errors of the fit (default STDOUT)
`:reset`	Return to original conditions of x, y, wts and npts.
`:ebars` [*errors/weights*]	The size of marker type '[hv]ebars' can show either standard deviations or relative weights.
`:function` [*value*]	Fitting function (power, chebyshev, legendre, spline3, or spline1)
`:transform` [*value*]	Set the transform type (none, logo, k50, k75)
`:fog` [*value*]	Change the fog level (or ":fog reset")
`:order` [*value*]	Fitting function order
`:quit`	Terminate HDFIT without updating database
`:/mark` string	Mark type (point, box, plus, cross, diamond, hline, vline, hebar, vebar, circle)

Additional commands are available for setting graph formats and manipulating the graphics. Use the following commands for help.

`:/help`	Print help for graph formatting option
`:.help`	Print cursor mode help

The value of fog can be changed interactively if you have reason to override the value written in the database by *spotlist*. You can reset the fog to its original value with the command ":fog reset". A common problem with defining the HD curve is that some of the calibration spot densities fall below fog. This is caused by either the low signal to noise at low densities or by making a poor choice of where to scan the fog level. These points are rejected from the fit when a transformation of the density is being made, as the transform cannot be evaluated for negative density. If the fog value or transformation type is interactively changed so this problem no longer exists, the spot densities are restored in the sample.

The parameters of the final fit are written to a database which then contains the information necessary to reinitialize the curfit package for applying the transformation in *hdtoi*.

4. Applying the Transform

4.1. HDTOI

Once the HD curve has been defined, it is applied to a density image in task *hdtoi*. Here the transformation is applied, as described by the fit parameters stored in the database. If more than one record of fit parameters is present, the last one is used. This means task *hdfit* can be repeated until an acceptable solution is found; the last solution will be used by *hdtoi*. On output, a new output image is written; the input image is left intact.

The transformation is accomplished by using a look-up table. All possible input values, from the minimum to maximum values found in the image, are converted to density using the scale value read from the database, and then to intensity using the fit parameters determined by *hdfit*. The input value is then the index into the intensity table: intensity = look_up_table (input_value).

A scaling factor can be applied to the final intensities, as typically they will be < 1.0. (The maximum log exposure in the NOAO wedge database is 0.0) By default, a saturated density pixel will be assigned the "ceiling" intensity of 30000 and the other pixels are scaled accordingly. The user is responsible for choosing a ceiling value that will avoid having significant digits truncated. The precision of the transform is unaffected by scaling the final intensities, although caution must be used if the output image pixel type is an integer.

The value of fog to be used is entered by the user, and can be either a number or a list of file names from which to calculate the fog value. The fog value is subtracted from the input image before the transformation takes place. Again, consider density values below fog. Two choices are available for these densities: the calculated intensity can be equal to the constant value 0.0 or equal -1.0 times the intensity determined for absolute (density).

5. Aligning Related HD curves

Calibration data sets from several plates can be combined once a shift particular to each set has been removed. "Different spot exposures define a series of HD curves which are parallel but mutually separated by arbitrary shifts in log exposure, produced by differing lamp intensities or exposure times. Generally, Kodak spectroscopic plates can be averaged if [1] they come from the same emulsion batch and box, [2] they receive identical hypersensitizing, [3] they are exposed similarly and [4] they receive the same development." *

5.1. HDSHIFT

Procedure *hdshift* calculates and subtracts a zero point shift to bring several related HD curves into alignment. The individual shifts are calculated by elimination of the first coefficient (Bevington, eqn 9-3):

$$a0 = \bar{y} - a_1\bar{X} - a_2\bar{X}^2 - \cdots - a_n\bar{X}^n$$

Here, the averages over y and X refer to individual calibration set averages; the coefficients a1, ... an were previously calculated using data from all calibration sets with task *hdfit*, and stored in the database. The a0 term is calculated individually for each database; this term represents the zero point shift in log exposure and will be different for each database.

On output, the log exposure values in each database have been shifted to the zero point shift of the first database in the list. The log exposure records are now aligned and it would be appropriate to run *hdfit* on the modified database list.

---

* "Averaging Photographic Characteristic Curves", John Kormendy, from "ESO Workshop on Two Dimensional Photometry", Edited by P. Crane and K.Kjar, p 69, (1980), an ESO Publication.

6. Testing the Transformation Algorithm

A test task is included to see if any numerical errors were introduced during the density to intensity transformation. It also evaluates truncation errors produced when an output image with integer pixels, rather than reals, is written.

6.1. SELFTEST

An intensity vector is generated from a density vector in two different ways. The first method uses the density vector and known coefficients to compute the intensity. The second method uses the curfit package to generate a look up table of intensities as done in task *hdtoi*. The residual of the two vectors is plotted; ideally the difference between the 'known' and 'calculated' intensity is zero.

Task *selftest* also plots intensity as a function of density for both integer and real output pixels. The user should investigate the plot with the cursor zoom and expand capabilities to determine if truncation errors are significant.

7. The Wedgefile Database

Task *dematch* reads a database and retrieves log exposure information for certain combinations of wedge number, photographic emulsion and filter. Those combinations included in the NOAO database are listed in the next section, although any calibration data can be included if the values are known. To modify the database, it is recommended that you generate a new file rather than add records to the existing file. This way, the modifications will not be lost when a new version of the IRAF system is released.

In the database, the information for each wedge makes up a separate record; each record starts with the word **begin**. Each record has a title field and can have multiple emulsion/filter fields. The number of log exposure values must be given, followed by the values written 8 per line. The order of the exposure data can be either monotonically increasing or decreasing. Here is an example:

```
begin   115
        title    MAYALL 4-M PF BEFORE 15APR74 (CHROME) [MP1-MP968]
        IIIAJ/UG2      16
                  0.000 -0.160 -0.419 -0.671 -0.872 -1.153 -1.471 -1.765
                 -2.106 -2.342 -2.614 -2.876 -3.183 -3.555 -3.911 -4.058
        IIAO/UG2       16
                  0.000 -0.160 -0.418 -0.670 -0.871 -1.152 -1.468 -1.761
                 -2.102 -2.338 -2.609 -2.870 -3.176 -3.547 -3.901 -4.047
```

7.1. Contents of the NOAO Wedgefile

The following table lists the wedge/emulsion/filter combinations available in the NOAO wedgefile database.

Wedge 24 **CTIO SCHMIDT WESTON TUBE SENSITOMETER.**
MONO/MONO

Wedge 48 **PALOMAR 48-INCH SCHMIDT STEP WEDGE.**
MONO/MONO

Wedge 84 **OLD 84-INCH SPOT SENSITOMETER (1967)**
MONO/MONO

Wedge 101 **SPOT BOX 4, KEPT IN SCHOENING-S LAB.**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4760	MONO/5200	MONO/5876
MONO/6470			

Wedge 115 **MAYALL 4-M PF BEFORE 15APR74 (CHROME) [MP1-MP968]**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4770	MONO/5200	MONO/5876
MONO/6470			

Wedge 117 **CTIO 4-METER P.F.**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4770	MONO/5200	MONO/5876
MONO/6470			

Wedge 118 **CTIO 4-METER CASSEGRAIN**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4760	MONO/5200	MONO/5876
MONO/6470	MONO/6900		

Wedge 119 **SPOT BOX 5, KEPT AT MAYALL 4-METER.**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4760	MONO/5200	MONO/5876
MONO/6470			

Wedge 120 **SPOT BOX 6, KEPT AT 2.1-METER.**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4760	MONO/5200	MONO/5876
MONO/6470			

Wedge 121 **SPOT BOX 8, KEPT IN SCHOENING’S LAB.**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4760	MONO/5200	MONO/5876
MONO/6470			

Wedge 122 **SPOT BOX 7, AVAILABLE AT KPNO NIGHT ASST’S OFFICE**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4760	MONO/5200	MONO/5876

MONO/6470C

Wedge 123 **MAYALL 4-M P.F. 15APR74 TO 21MAY74 [MP969-MP1051]**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4770	MONO/5200	MONO/5876
MONO/6470			

Wedge 129 **MAYALL 4-METER P.F. AFTER 21MAY74 [MP1052-->]**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4760	MONO/5200	MONO/5876
MONO/6470			

Wedge 130 **MAYALL 4-METER CASS CAMERA.**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4760	MONO/5200	MONO/5876
MONO/6470			

Wedge 138 **TRAVELLING BOX AFTER 06JAN78.**

IIIAJ/UG2	IIAO/UG2	IIIAJ/*5113	IIAO/*5113
IIAO/GG385	IIIAJ/CLEAR	IIIAJ/GG385	IIAD/GG495
127/GG495	098/RG610	127/RG610	IVN/RG695
MONO/4363	MONO/4770	MONO/5200	MONO/5876
MONO/6470			

Wedge 201 **TEN UCLA SPOTS (H. FORD, 10JAN78)**

MONO/MONO