

CCDUTIL

Image Processing Utilities for the ST-4

Table of Contents

<i>Introduction.....</i>	<i>1</i>
<i>Running the Program.....</i>	<i>3</i>
<i>Image I/O Menu.....</i>	<i>6</i>
<i>The Display Menu and Graphics Mode</i>	<i>12</i>
<i>PC Menu.....</i>	<i>19</i>
<i>Operations Menu.....</i>	<i>20</i>
<i>Appendix A - Image File Format.....</i>	<i>29</i>
<i>Appendix B - TIFF File Format.....</i>	<i>31</i>
<i>Appendix C - FITS File Format.....</i>	<i>33</i>

SBIG - Santa Barbara Instrument Group

Copyright Notice

This manual and the software described in it were developed and are copyrighted by Santa Barbara Instrument Group (SBIG). Neither the manual or the software may be copied in whole or in part except as follows:

- 1) You may make backup copies of the software for your own use provided that they bear SBIG's copyright notice.

CCDUTIL Manual
Version 1.0
Printed September 1990

©1990 Santa Barbara Instrument Group
1482 East Valley Road, Suite 601
Santa Barbara, CA 93108
Telephone (805) 969-1851
FAX (805) 969-0299

CCDUTIL - Image Processing Utilities for the ST-4

INTRODUCTION

The CCDUTIL program is one in a series of programs from Santa Barbara Instrument Group to enhance the operation of the Model ST-4 Star Tracker and Imaging Camera. The program contains image processing utilities and special file utilities for interchanging image files from the ST-4 with other programs. The utilities include image translation and rotation with sub-pixel accuracy, flat field correction of images, filtering, and scaling. The CCDUTIL program uses image files previously captured and saved with the CCD software that came with your ST-4 and does not contain the routines necessary for interfacing directly to the ST-4. For that you will continue to use the CCD program.



Getting Started

This section describes what you need to do to get the CCDUTIL software up and running on your PC including installing the software. If you've spent any time with the CCD program included with the ST-4 you'll feel right at home and can briefly scan this and the following section.

Making a Backup Copy

The first thing you should do is make a backup copy of your CCDUTIL diskette and put the original away in a safe place. The program is not copy protected so you can use the DOS "DISKCOPY" command or your favorite utility. This doesn't mean the software isn't copyrighted though, which it is. Please don't give copies of the software away.

Making a backup copy is especially important if you intend to run the CCDUTIL program from a floppy diskette.

Installing on a Hard Disk

If you have a hard disk on your system and wish to install the software on it we suggest you install it in the directory containing your CCD program. In this way the two programs can share access to the graphics driver programs (CGA.BGI, EGAVGA.BGI, etc.), and you will only need to copy the two files "CCDUTIL.EXE" and "CCDUTIL.CFG". If however you wish to, you may install the CCDUTIL program in its own directory, but in this case you will also need to copy the graphics driver programs as well.

Running the CCDUTIL program is just a simple matter of making the directory containing the CCDUTIL program be the current working directory using the DOS "CD" command if necessary, and running the program by typing "CCDUTIL " followed by hitting the "Enter" key. If you're running from a floppy diskette and are swapping diskettes to get access to system files or data files, you will need to insure that the program diskette is installed in the disk drive when you quit the program. The program remembers the user's settings in the CCDUTIL.CFG file which gets updated when you quit the program.

Elements of the User Interface

The CCDUTIL program interacts with the user through a friendly and efficient user interface containing pull-down menus and dialog boxes, and operates in two distinct modes: Text mode and Graphics mode. The Text mode is activated when the program is first run and contains the pull-down menus, dialog boxes, and other items requiring an interactive role with the user. The Graphics mode is used for displaying images and analyzing them with cross-hairs, etc. This section describes the elements which together make up the user interface.

Menu Bar and Menu Commands

At the top of the screen (in text mode) is the menu bar showing the different menu titles or commands (**Image I/O**, **Operations**, etc.). At any time only one menu in the menu bar is highlighted, and the highlighting can be moved from menu to menu using the left and right arrow keys. Once a menu title is highlighted, hitting the "Enter" key causes one of two things to happen: Either a pull-down menu is revealed with several sub-commands (as is the case with the **Image I/O** command) or a dialog box is shown (as is the case with the **Display** command). Either of these can be exited or canceled by hitting the

"Esc" key. How each of these items interacts with the user is described in individual sections below.

Note:

Commands can also be invoked from the menu bar by hitting the first letter of the intended command. For example, hitting the "I" key invokes the **Image I/O** command, revealing its pull-down menu.

Pull-Down Menus

Pull-down menus show several commands arranged vertically, with one command highlighted. The highlighting can be moved from command to command using the Up and Down Arrow keys (or the Tab and Shift-Tab key combinations). Once a command is highlighted it can be invoked by hitting the "Enter" key. Invoking commands can cause a dialog to be displayed or can cause some immediate action, depending on the individual command.

Note:

Commands in menus can also be invoked directly once the pull-down menu is visible (without moving the highlighting) by hitting the key corresponding to the highlighted capital letter shown in the command.

Dialogs

Dialogs are outlined boxes drawn in the center region of the screen for interacting with the user and typically contain several parameters which can be changed by moving to the desired line and changing the setting. You move the flashing cursor up and down through the dialog parameters using the Up and Down Arrow keys (or the Tab and Shift-Tab key combinations).

Note:

In the dialogs, the descriptive text to the left of each parameter contains a single highlighted character. This character indicates that you can move the flashing cursor directly to that parameter by pressing the "Alt" key in conjunction with the highlighted character

The method used to change a parameter's setting depends on the type of the parameter, of which there are two: ones where you select a single choice from a list of choices and ones where you type in some number or text. For the first type, you select the desired setting by using the Left and Right Arrow keys. In the second case you simply type in the desired setting. You can use the "Backspace" key to edit the text or use the "Del" key to completely erase all the text entered in the parameter. When you are done setting the parameters in the dialog, you can proceed on to execute the command by hitting the "Enter" key or abort the command by hitting the "Esc" key.

Status Box

Towards the bottom of the Text mode display is the Status box which is used by the program to convey passive information to the user such as the introductory information presented when the program is first run. You will want to check the status box periodically for this information.

Data Buffer Information Box

Just below the Status box is the Data Buffer information box which indicates whether any image data is currently held in memory, whether that information has been saved on disk or not, and whether the image data has been zoomed (and thus could be unzoomed).

Graphics Display Mode

The program switches to Graphics mode when images need to be displayed or analyzed, such as after executing the **Display** command. You can switch back to Text mode from Graphics mode by hitting the "Esc" key.

The **Image I/O** menu contains commands which are used to retrieve and store images from/to disk, and commands for creating directories and deleting files. Central to the use of the **Image I/O** menu is the File Path, File Filter, and the Directory Dialog which are explained in detail below.

The File Path (which can be set using the **Path/Filter** command in the **Image I/O** menu) tells the CCDUTIL software where to look for files to display in the directory dialog and where to save files. This should be set to the directory where you save your image data files, and can be changed easily if you have created multiple directories for your images. If, for example, your image files have been saved in the DATA directory which resides at the root level of your C: hard disk, you would set the File Path to "C:\DATA". Although they serve similar purposes, you should not confuse the File Path with DOS's Path command. The File Path is only used by the CCDUTIL software, and must be set using the **Path/Filter** command in the **Image I/O** menu.

Note:

If you specify a blank File Path (to use the current DOS working directory), the program will substitute the equivalent File Path ".\".

The File Filter allows you to exclude certain files from showing in the Directory Dialog by specifying a "match string". Only files matching the File Filter will be shown in the Directory Dialog. You can use the DOS wild card characters "*" and "?" in the File Filter, and specifying a File Filter other than the all-showing "*.*" will cause some files not to appear. For example setting the File Filter to "*.ST4" will cause only files with the extension ".ST4" to appear in the directory dialog.

The Directory Dialog is shown whenever you need to choose a file on the disk for loading, deleting, etc. Rather than having you type in the name of the file, the program displays all the files (that match the File Filter) in the current File Path. You can then use the four arrow keys to select the desired file. For directories which contain more than 40 files, the PgUp and PgDn keys allow you to page through the files 40 at a time. The files are sorted into alphabetical order, and you can move the selection cursor to the first file starting with any letter by hitting that letter on the keyboard. Additionally, the directory dialog shows the current path and filter at the top of the box containing the files, the current page and number of pages of files and the amount of free space on the disk at the bottom of the box, and as the cursor is moved from file to file, the file's name, size and creation date are shown in a box below the files.

Load Command

The **Load** command is used to retrieve ST-4 image files from the disk. Once the File Path and File Filter have been set as desired, invoking the **Load** command reveals the Directory Dialog. There you select the desired file and hit the "Enter" key. The Status box will display a message saying it is loading the file, and then another when the file has been completely loaded. If any errors occur, the program will warn you.

Save Command

The **Save** command allows you to save the image in memory onto the disk as a standard ST-4 image file, the format of which is described in Appendix A. After setting the File Path if necessary, invoking the **Save** command will present you with a dialog where you can specify the file's desired name. At this point you can hit the "Enter" key and the file will be saved, or you can hit the "Esc" key and the whole process canceled. While the file is being saved, the Status box will

show a message to that effect, and then when the save has been completed another message is shown. Should any errors occur, the program will warn you.

Save TIFF Command

The **Save TIFF** command allows you save the ST-4 image in memory using the industry standard TIFF (tagged interchange file format) for import into other image processing or graphics programs. Invoking the **Save TIFF** command brings up a dialog where you can specify the file name and some additional information to be saved with the file such as the Observer, and a Comment. While most other programs will not use this extra information, it is recommended in the TIFF specification and has been included for completeness. After these items have been specified, hitting the "Enter" key causes the file to be saved (in the directory specified by the File Path) using the uncompressed format of the TIFF specification. It can then be imported into other PC programs such as PageMaker as a TIFF graphic file. The image is saved without applying the *Background* and *Range* parameters from the **Display** command, so if you desire to mimic the displayed image in terms of brightness and contrast you should use the **Push** or **Scale** commands (discussed in a later section) to alter the image prior to using the **Save TIFF** command. Also, you may wish to refer to Appendix B for a complete description of the TIFF files written by the CCDUTIL program.

Save FITS Command

The **Save FITS** command allows you to save the ST-4 image in memory using the FITS (flexible image transport system) format common to astronomical image processing software (such as PC-VISTA). Invoking the **Save FITS** command brings up a dialog where you can specify the

file name and some additional information to be saved with the file as described below:

Object:

Set this string to a descriptive title of the object contained in the image such as "M51, the Whirlpool Galaxy".

Date of observation:

Set this string to the date the object was observed using a 2 character month, day, and year such as "09/01/90".

Institution:

Set this string to the name of the observatory where the image was made such as "Ocean Highlands Observatory".

Telescope:

Set this string to a description of the telescope used for the image such as "C11 at f/10".

Observer:

Set this string to the observer's name such as "John Doe".

Comment

Include in this string any extra information about the image you think some one looking at the FITS file might want to know such as the observation time, exposure time, etc.

Note:

The comment defaults to the Image Note attached to the image using the **Edit Parameters** command, and changing the Comment will not change the Image Note.

After these items have been specified, hitting the "Enter" key causes the file to be saved (in the directory specified by the File Path). As

with the **Save TIFF** command, you can use the **Push** or **Scale** commands to alter the image's contrast prior to using the **Save FITS** command. Also, you may wish to refer to Appendix C for a description of the FITS files written by the CCDUTIL program.

Create Directory Command

The **Create Directory** command allows you to create a new data directory without leaving the CCDUTIL program. Invoking the command brings up a dialog where you can name the directory, and optionally select to make it the current directory. This automatically sets the File Path to the newly created directory. If any errors occur while creating the directory you will be warned.

Note:

The **Load** command can not be used on an empty directory (it will warn you), so don't let that cause you to believe that the **Create Directory** command did not work. Once you have saved a file in the new directory the **Load** command will work correctly.

Delete Command

The **Delete** command allows you to delete or remove files from the directory specified by the File Path. When the command is invoked, the directory dialog is shown. Files are deleted by positioning the cursor over the desired file and then hitting the "Ctrl-D" key combination. After a file has been deleted, its name is replaced with "-deleted-", and multiple files can be deleted at one time by repositioning the cursor and hitting "Ctrl-D". When you are all through with the **Delete** command, hitting the "Enter" or "Esc" keys exits the command.

Important Note:

The process of deleting files can not be undone, and you are not asked by the software to confirm that you actually want to delete the file. Be careful so as to not delete the wrong file or files.

The **Display** command/menu is used to switch the program from Text mode (with the menu bar, menus, etc.) to Graphics mode where the image is displayed. Invoking the **Display** command brings up a dialog with several parameters discussed below.

Auto contrast:

Setting this item to *Yes* causes the software to pick values for the *Background* and *Range* parameters based upon the image data. You will usually want to use Auto contrast when first viewing an image, and then later you can redisplay the image, specifying the contrast parameters to fine tune the display.

Background:

When the *Auto contrast* item above is set to *No*, the image is displayed with all pixel values below the *Background* level as off or black. Raising this item cuts off more dim pixel values, and lowering it shows more low intensity pixels.

Range:

When the *Auto contrast* item above is set to *No*, this item controls the image's contrast. Pixels between the *Background* level and the *Background* level plus the *Range* are displayed using the intensity capabilities of your display adapter and monitor. Pixel values above the *Background* + *Range* level are saturated on the display. Increasing this item decreases the image's contrast and vice versa.

Smoothing:

Setting this item to *Yes* causes the displayed image to be smoothed or lowpass filtered. The smoothing doesn't actually affect the image data; it is accomplished by averaging displayed pixel intensities with their neighbors.

Negative image:

Setting this item to *Yes* causes the image to be displayed as a negative, with brighter pixels being black and dimmer pixels being white.

Display mode:

When this item is set to *Analysis*, the image is displayed on the right of the graphics display, and the image can be analyzed with a crosshair, etc. When this item is set to *Photo*, the image is centered on the graphics display for photographic purposes.

Color select:

This item is only available for users with VGA display adapters. It controls whether the image is displayed in grey scale or using false colors (like the EGA mode display).

Note:

The **Display** command does not modify the image data in the process of displaying it. Any changes to the image's contrast, smoothing, etc. are only for display purposes.

After the items in the *Display* dialog have been set, hitting the "Enter" key causes the program to switch to Graphics mode and display the image along with any image note at the top of the image and a menu below the image (assuming you've selected the *Analysis* setting in the *Display mode* parameter). You can exit from the **Display** command back to text mode by hitting the "Esc" key. Additionally, if the *Display mode* item from the *Display* dialog was set to *Analysis*, you can invoke the *Crosshairs* mode or the *Markers* modes discussed in the next sections.

Crosshairs Mode

The *Crosshairs* mode is entered by hitting the "X" key from the *Analysis* display mode mode. This shows a crosshair superimposed upon the image, a series of parameters to the left of the image, and a

new **X-Hair** menu at the bottom of the display, the commands of which are described below. Finally, you can exit the Crosshairs mode by hitting the "Esc" key.

Backgnd:

By positioning the cursor and hitting the "B" key, the software uses the data under the cursor as representative of the background level for magnitude calculations. For accurate measurements of magnitudes you should set the Background in a region of the image void of stars or nebulosity.

Star:

By positioning the cursor and hitting the "S" key, the software uses the pixel position under the cursor as the reference position for Separation measurements. For example to measure the separation between two stars you would position the cursor over one of the stars, hit the "S" key, then reposition the cursor over the second star.

Toggle size:

By hitting the "T" key the software cycles the box size used in measuring the Smoothed Pixel value and the Magnitudes from 3 x 3 pixels through 11 x 11 pixels.

The crosshair parameters displayed to the left of the image are updated as the crosshair is moved around the image. The Arrow keys move the cursor by 1 or 5 pixels per keypress depending on whether the "NumLock" or "Shift" keys are down.

Note:

You may find it easiest to move the cursor by keeping your left hand on the Shift key and using your right hand to work the keypad. In this way, you control the speed of the cursor by pressing or releasing the Shift key. Also, you can use the i,j,k, and m keys (and their Shifted versions) as a virtual keypad to move the cursor.

Each of the parameters from the Crosshairs mode are described below:

Pixel:

These are the Crosshair's X and Y coordinates, with Pixel 1,1 being in the upper left hand corner of the image.

Value:

This is the pixel value or intensity of the pixel directly under the crosshair and will range from 0 through 255.

Sm-Value:

This is the average pixel value of the box of pixels centered under the crosshair. The box size is controlled with the **Toggle size** command.

Mag.:

This is the magnitude of the object inside the box of pixels centered under the crosshair. The magnitude is calculated by summing the contributions of all the pixels in the box with the background level subtracted. The calculated magnitude also depends on the Exposure time, the Aperture and the CCD's Response factor which can be changed with the **Edit Parameters** command in the **Operations** menu.

DifMag:

This is the diffuse magnitude, or magnitude per square arcsecond, of

the object inside the box of pixels centered under the crosshair. In addition to the items affecting the magnitude calculation, the diffuse magnitude depends on the Focal length of the telescope used.

Sep.:

This is the separation in arcseconds between the current position of the crosshair and the position marked with the **Star** command.

Angle:

This is the orientation of the line drawn between the current position of the crosshair and the position marked with the **Star** command, measured in degrees clockwise from vertical

Boxsize:

This the size of the box used in making the average pixel, magnitude and diffuse magnitude calculations, and is changed using the **Toggle size** command.

Markers Mode

The Markers mode is entered from the display or graphics mode by hitting the "M" key, and is used for marking the position of pairs of reference points in images for aligning those images.

To align one image to another you must specify two points in each of the images. One image is referred to as the Reference image, and the second image is called the Source image. The process of aligning images actually involves translating and rotating the Source image to align it with the Reference image, which itself does not get modified.

In each of the two images, you must specify the position of two objects (stars). The position of these objects are referred to as the Pivot and Angle Reference points. The alignment of the Source image to the Reference image is done by the computer by translating the Source image until its Pivot point aligns with the Reference image's Pivot point, and then rotating the Source image until the orientation of the

line between the Source image's Pivot and Angle Reference points matches the orientation of the line between the Reference image's Pivot and Angle Reference points. This is shown diagrammatically below.

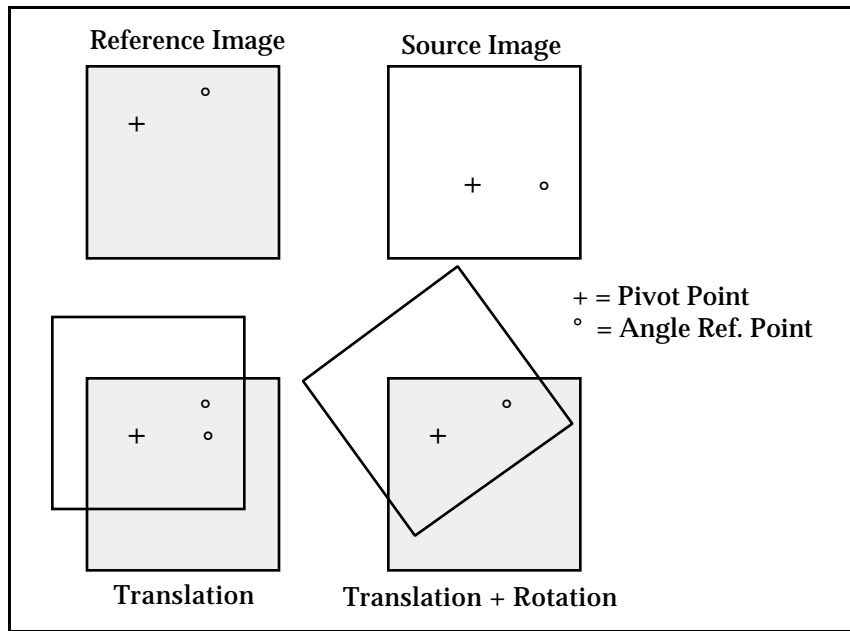


Figure 1 Image Alignment

The Markers mode allows you to mark and record the position of the reference points in the images using the F1 through F4 function keys as described below. Pressing one of these keys causes the software to calculate the X and Y centroid of the data under the cursor and retain those coordinates for later use with the **Align** command from the **Operations** menu.

F1:

Use this to mark the position of the Pivot point in the Reference image.

F2:

Use this to mark the position of the Angle Reference point in the Reference image.

F3:

Use this to mark the position of the Pivot point in the Source image.

F4:

Use this to mark the position of the Angle Reference point in the Source image.

Alignment of the two images can then be performed as discussed under the **Operations** menu.

The **PC** command/menu is used to fine tune the operation of the CCDUTIL program to the capabilities of your PC. The parameters in the PC Setup dialog are discussed below:

Graphics card:

Set this item to *Auto* to have the software choose the best possible display mode for your particular PC, or set it to the type of display adapter you have installed in your system. Users with VGA can use all modes except Hercules, users with EGA can use EGA and CGA.

Color display:

Usually you should set this item to *Yes* if you have a color monitor attached to your system, although you should experiment with the setting to see its effects.

Aspect ratio:

Use this item to adjust the aspect ratio of the Photo display mode for a square picture.



The commands in the **Operations** menu modify the image which has been previously loaded into memory, replacing the image with the modified or operated upon version. After invoking one of the commands in the **Operations** menu the image will need to be saved on disk using the **Save** command (**Image I/O** menu) to permanently record the changes made. When you save the image you may also wish to give the file a new name, thus keeping the original. The **Undo** command allows you to undo the changes made to the image by the last command invoked from the **Operations** menu, but it operates on the image in memory, not on disk.

Undo Command

Although the **Undo** command is at the bottom of the **Operations** menu, it is described first because it allows you to undo the effects of the last command from the **Operations** menu you performed on an image. You are asked to verify the undo operation, which itself can not be undone. Also, in the rare case where there is not enough memory for an undo buffer, you are warned when the CCDUTIL program is first run that the **Undo** command will be inoperative.

Align Command

The **Align** command is used to align images to one another, and is aided by the Markers mode of the **Display** command described above. If you haven't read that section, you should do so because it describes the nomenclature used in the **Align** command.

When the **Align** command is invoked a dialog is shown where you need to specify the X and Y coordinates of the Pivot and Angle Reference points in the Source and Reference images. Procedurally the way you align a series of images is as follows:

1. Load the Reference image and mark the position of the Pivot and Angle Reference points using the F1 and F2 function keys in the Markers mode of the **Display** command.
2. Load a Source image, and mark the position of the corresponding Pivot and Angle Reference points using the F3 and F4 function keys in the Markers mode of the **Display** command.
3. Invoke the **Align** command to align the Source image to the Reference image.
4. Save the aligned Source image, using a different name.
5. Repeat steps 2 through 4 until all desired images of a group have been aligned.

Offset Command

The **Offset** command subtracts a constant value from each of the pixels in the image, and can be used to remove the majority of the background from a series of images which you wish to co-add without the cumulative background reducing the possible dynamic range of the summed image. Do not remove the background all the way down to zero because the statistical variation in background pixel values means you may actually be removing valid data from the image which could be detrimental (leave in about 4 units of background). Additionally, the **Offset** command allows you to specify a negative offset, which actually adds a constant to each of the pixels in the image.

Push Command

The **Push** command increases the contrast of the image by subtracting an offset from each pixel, and then multiplying by a second constant. The effect on the image is the same as the visual effects produced by the *Background* and *Range* parameters of the **Display** command except that the actual image data is modified, rather than just temporarily for display purposes. The *Background* parameter sets the black level of

the sky background, and the *Range* parameter sets the contrast or white saturation level of the image.

Invoking the **Push** command shows a dialog with the *Background* and *Range* parameters set to the values used in the **Display** command. Thus it is quite easy to use the **Display** command to get the image's appearance desired and then use the **Push** command to permanently modify the image. Once an image has been "Push"ed. Then it can be displayed with the background set to 0 and the Range set to 255.

Mathematically, the **Push** command modifies the pixels in the image by the formula:

$$P'(x,y) = (P(x,y) - \text{Background}) * \frac{\text{Range}}{255}$$

Scale Command

The **Scale** command works like the **Push** command described above in that it subtracts a constant value from each pixel and then multiplies by a second constant except that the multiplicative scale factor is specified expressly and can be less than 1.0. Invoking the **Scale** command reveals a dialog where you specify the scale factor and the offset. In addition to modifying the image, the image's *CCD Response factor* parameter is scaled by the scale factor.

Mathematically, the **Scale** command modifies the pixels in the image by the formula:

$$P'(x,y) = (P(x,y) - \text{Offset}) * \text{Scale}$$

Translate Command

The **Translate** command allows you to translate or offset the image in X and in Y, with the translation not being limited to integral values. When the **Translate** command is invoked you are presented with a dialog where you specify the X and Y offsets. Positive offsets moves

the image to the right or down, and negative offsets move the image left or up. Non-integral translations are done by linear pixel interpolation where any translated pixel is a weighted sum of the four nearest untranslated pixels.

Sharpen Command

The **Sharpen** command highpass filters the image which enhances or sharpens regions where the pixel intensities are changing. The **Sharpen** command does not require any user input, and replaces each pixel in the image with a weighted sum/difference of the pixel and its eight neighbors.

Smooth Command

The **Smooth** command lowpass filters the image which smooths regions where the pixel intensities are changing. The **Smooth** command does not require any user input, and replaces each pixel in the image with a weighted sum of the pixel and its eight neighbors.

Note:

It is often best to use the **Push** command to increase the range of pixel values in an image to give the **Smooth** command some room to work with.

Add Image Command

The **Add Image** command allows you to co-add two images, and one of the images can be translated in X and Y relative to the other by integral numbers of pixels. Additionally a constant can be subtracted from the sum of the two images which removes the effects of reduced dynamic range due to large accumulated background levels. Procedurally the way you co-add two images is by loading the first

image into memory, co-adding the second image off the disk using the **Add Image** command and then saving the resulting co-added image.

When the **Add Image** command is invoked you are presented with the Directory Dialog where you should select which image you want to co-add to the image currently in memory. Once the desired file has been highlighted using the Arrow keys, hitting the "Enter" key reveals a second dialog where you specify the X and Y offsets or the amounts the second image (the one on disk) should be shifted relative to the first (the one in memory) for alignment purposes and the Count offset which is the amount to subtract from the sum of the two images.

To determine the proper settings for the *X offset* and *Y offset* parameters you must individually load each of the images you wish to co-add and find the pixel coordinates of some reference object in each image prior to using the **Add Image** command. For example lets say you have three images M51A, M51B, and M51C that you want to co-add, and you determine the (X,Y) coordinates of some star (the same star in all three images) are (121,34), (118,36) and (130,30). Additionally you determine that the sky background level in each of the three images is 25 counts. To co-add these three images you would then:

1. Load the M51A image using the **Load** command in the **Image I/O** menu.
2. Invoke the **Add Image** command, select the M51B image and specify an X offset of 3, a Y offset of -2 and a Count offset of 40. The X offset is 3 because you must move M51B three pixels to the right to align it with M51A (118 to 121 is 3). For the same reason, the Y offset is -2 (36 to 34 is -2). The Count offset is determined to be 40 by noting that we will add two images, each having a background level of 25, for a total of 50, but we don't want to remove all the background because there is some variation around the 25 level and we want to be sure we don't actually subtract off some real data. After hitting the "Enter" key to do the addition we have the sum or result of the co-addition of the first two images in memory.
3. Invoke the **Add Image** command one more time, select the M51C image and specify an X offset of -9, a Y offset of 4, and

a Count offset of 25. The X offset is 9 because you must move M51C 9 pixels to the left to align it with M51A (130 to 121 is -9). For the same reason, the Y offset is 4 (30 to 34 is 4). For the Count offset we just select the third image's background level since we are co-adding it to the result of the first co-addition which essentially only has a background level of 10 which is our safety margin.

4. Save the resulting image as M51SUM using the **Save** command in the **Image I/O** menu.

Flat Field Command

The **Flat Field** command allows you to correct images for the effects of nonuniform pixel responsivity across the CCD array. Although the individual pixels in the CCD accumulate charge at approximately the same rate given a source of uniform intensity, there are small deviations. For example, if you were to take an image of a uniformly illuminated grey screen, not all pixels would have the same reading. Some would be slightly higher than the average, and some would be slightly lower. The **Flat Field** command allows you to correct for this effect. Although these effects are small (typically less than 5%), Flat Field correcting images is important when you wish to make extremely critical brightness or magnitude measurements. It is doubtful whether you could visually tell the difference between a corrected and uncorrected image, so you must decide whether to take the time to correct any or all of your images. The **Flat Field** command is very useful for removing the effects of vignetting that may occur when using a field compression lens.

In order to use the **Flat Field** command, you must first make a Flat Field Calibration Image. This image is of a uniform source (across the CCD array), and is used to correct other images. The way you make the Calibration file is by taking an image of a grey target, adjusting the exposure duration to achieve an average pixel value of approximately 150 to 200, after subtracting a Dark Frame of equal exposure duration. The higher the average pixel value the more precise the resulting

corrected image, but you must not let pixels saturate (at or above approximately 250) prior to the Dark Frame subtraction or else the nonlinearity associated with the saturation will adversely affect the process. For a uniform grey source you may be able to just take an image of the inside of your dome, or a uniform region of a non-dark sky. Use an exposure comparable to the image exposure for best results. No improvement in accuracy will result for flat field exposures longer than 30 seconds. Also, make the flat field exposure with the same telescope-CCD configuration used to capture stellar images. After making the Calibration Image (remembering that it must have a Dark Frame subtracted from it) you should save it on disk using a name such as "FLAT" where it can be easily accessed. Depending on how much you use the **Flat Field** command to correct images, you may wish to make several copies of the image, placing one in each of the data directories you will be using, and you will surely want to make a backup copy in case the original gets damaged or accidentally erased.

To Flat Field correct an image, you first use the **Load** command to load the desired image (not the Flat Field Correction Image), and then invoke the **Flat Field** command. You are then shown the Directory Dialog where using the cursor, select the Flat Field Correction Image. When you hit the "Enter" key, the Status box shows a message indicating the correction is in progress, then another message when it has been completed. Should any errors occur, you will be warned.

Subtract Image Command

The **Subtract Image** command allows you to subtract, on a pixel by pixel basis, an image on disk from the one in memory. Invoking the **Subtract Image** command reveals the Directory Dialog where you should select the image file you want subtracted using the cursor keys. After highlighting the desired file, hitting the "Enter" key proceeds with the subtraction. If any error occurs you are warned.

Typically you will use the **Subtract Image** command to remove the effects of dark current and pattern noise from exposures by capturing two

files of equal exposure duration, one of the object (called the light frame) and one with the telescope covered (called the dark frame). Both these images need to be saved on the disk after they are captured, and later the light frame loaded into memory (using the **Load** command) and the dark frame subtracted from it (using this command), and the resulting difference image saved on disk. If you wish to co-add a sequence of images, you will co-add the difference images, first subtracting a dark frame from each of the light frames prior to using the **Add Image** command to co-add the images.

Edit Info Command

The **Edit Info** command allows you to view or edit the information attached to the image such as the exposure time, etc. The parameters in the Edit Info dialog are discussed individually below:

Exposure time:

This was the duration of the exposure, or in the case of co-added images the total exposure time of all the combined images. The value of this parameter is maintained by the CCD and CCDUTIL programs and shouldn't need to be changed. Its setting affects the calculation of the Magnitude and Diffuse Magnitude parameters from the Crosshair mode of the **Display** command, where increasing the exposure time will lead to an decreased value of Magnitude or Diffuse Magnitude.

Focal length:

This was the focal length of the telescope used to make the image, and determines the image's field of view. Its setting affects the calculation of the Diffuse Magnitude and the Separation parameters from the Crosshair mode of the **Display** command. The focal length can be accurately set by measuring wide double stars and adjusting this parameter to achieve the correct separation.

Aperture:

This was the aperture of the telescope used to make the image. Its setting affects the calculation of the Magnitude and Diffuse Magnitude parameters from the Crosshair mode of the **Display** command.

Response factor:

This was the CCD's response or sensitivity for the exposure, and its setting affects the calculation of the Magnitude and Diffuse Magnitude parameters from the Crosshair mode of the **Display** command. The CCDUTIL program maintains this variable as the **Push** and **Scale** commands are applied to the image, and you can adjust it to calibrate the magnitude calculations based upon a known star. Increasing the response factor will lead to an decreased value of Magnitude or Diffuse Magnitude (Magnitude is inversely proportional to response factor).

Note:

You can store a message up to 78 characters in length in the note, and possible uses are the object's name and the date and time of the exposure.

This appendix describes the image file format used by the CCD and CCDUTIL programs for saving image files, and is included for users who wish to write their own image processing or translation routines.

The image files contain the 8-bit pixel data for the 192 horizontal by 165 vertical pixel images as well as the telescope calibration factors and file annotation.

As shown below in Figure A1, the first 31680 bytes (192 x 165) of the file are the pixel data, in left to right, top to bottom order: The first byte corresponds to the left-most pixel in the top line, the 2nd byte corresponds to the 2nd pixel in the top line, the 193rd byte corresponds to the left-most pixel on the 2nd line, etc. The data should be interpreted as unsigned bytes (values from 0 through 255).

Pixel x,y	1,1	2,1	3,1	...	192,1	1,2	2,2	...	1,165	...	192,165
Byte:	1	2	3	...	192	193	194	...	31488	...	31680

Figure A1 Image Data Bytes in the Image File

After the 31680 bytes of image data, the telescope parameters are stored in a "166th" line of 192 bytes, making the total file size be 31872 bytes. The data on this 166th line is written in text using ASCII characters. ASCII was chosen so that it could be easily interpreted using most programming languages. As shown below in Figure A2, the first byte of the 166th line is a lowercase 'v' character (118 in decimal, which signifies the total length of ASCII data on the 166th line). Bytes 2 through 79 (78 bytes total) are the file's annotation or note. The annotation is left justified and padded with spaces on the right to fill out the 78 character field width. The next 10 bytes (80 through 89) are the exposure or integration time in $\frac{1}{100}$ ths of a second. This field and the next three fields are right justified, padded with spaces as required

on the left to fill out the 10 character field widths. The next 10 bytes (90 through 99) are the focal length in inches. Bytes 100 through 109 are the aperture area in square inches, and finally bytes 110 through 119 are the image calibration factor. The remaining bytes (120 through 192) on the 166th line are reserved for future use.

166th line:	v	File Annotation	Exposure Time	Focal Length	Aperture Area	Calibration Factor	reserved
Field width:	1	78	10	10	10	10	73

Figure A2 166th Line Containing Image Parameters

This appendix describes the TIFF file format created by the CCDUTIL program when the **Save TIFF** command is used. It assumes the user is familiar with the TIFF format, and makes no attempt to describe the general TIFF requirements. Users who require the TIFF specification can contact:

Aldus Corporation
411 First Avenue South
Suite 200
Seattle, WA 98014
Phone (206) 628-2320

The CCDUTIL program saves the image in the TIFF file with the following attributes:

- The file format is least significant bytes first.
- The first and only Image File Directory (IFD) follows directly after the 8 byte header.
- The IFD contains 19 elements which are in the following order:
 1. A declaration of a new sub-file.
 2. An Image Width of 192 pixels.
 3. An Image Height of 165 pixels.
 4. A Bits Per Sample of 8.
 5. A compression type of 1 for no image compression.
 6. A Photometric Interpretation of 1 for an 8 bit greyscale image.
 7. The Image Description string of the Comment specified by the user in the **Save TIFF command**.
 8. A Make string set to "SBIG"
 9. A Model string set to "ST-4 Imager"
 10. A Strip Offset entry for 5 strips of 6336 bytes (33 lines) each.
 11. A Samples Per Pixel of 1.
 12. A Rows Per Strip of 33.
 13. A Strip Byte Counts entry for the 5 strips of 6336 bytes (33 lines) each.

14. An X Resolution of 192/4 pixels per inch for a 4 inch image.
 15. A Y Resolution of 165/4 pixels per inch for a 4 inch image.
 16. A Resolution Unit of 2 for inches.
 17. A Software string of "CCDUTIL version 1.0"
 18. A Date Time of the creation date and time.
 19. An Artist string of the Observer specified by the user in the **Save TIFF** command.
- Immediately following the IFD are the following:
 1. The 5 Strip Offsets (longs).
 2. The 5 Strip Byte Counts (longs).
 3. The X Resolution (rational).
 4. The Y Resolution (rational).
 5. The Artist (string).
 6. The Date Time (string).
 7. The Make (string).
 8. The Model (string).
 9. The Software (string).
 10. The Description (string).
 - Immediately after that are the 5 strips of image data.

This appendix describes the FITS file format created by the CCDUTIL program when the **Save FITS** command is used. It assumes the user is familiar with the FITS format, and makes no attempt to describe the general FITS requirements. Users who require the FITS specification can reference:

"FITS: A FLEXIBLE IMAGE TRANSPORT SYSTEM"
by D.C. Wells, E.W. Greisen AND R.H. Harten
ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES
June 1981, page 363

The CCDUTIL program saves the image in the FITS file with the following attributes in the order listed:

- The SIMPLE variable is set to "T" indicating a file adhering to the simple format.
- The BITPIX variable is set to 8 indicating 8 bits per pixel.
- The NAXIS variable is set to 2 indicating a 2 dimensional data array.
- The NAXIS1 variable is set to 192 indicating 192 pixels across a row.
- The NAXIS2 variable is set to 165 indicating 165 pixels down a column.
- The OBJECT variable is set to the *Object* string supplied by the user in the **Save FITS** command.
- The DATE variable is set to the file creation date.
- The DATE-OBS variable is set to the *Date of observation* string supplied by the user in the **Save FITS** command.
- The ORIGIN variable is set to the *Institution* string supplied by the user in the **Save FITS** command.
- The INSTRUME variable is set to "SBIG ST4".

- The TELESCOP variable is set to the *Telescope* string supplied by the user in the **Save FITS** command.
- The OBSERVER variable is set to the *Observer* string supplied by the user in the **Save FITS** command.
- A COMMENT line is given with the *Comment* string supplied by the user in the **Save FITS** command.
- Six COMMENT lines are written indicating the file was created by the CCDUTIL program from SBIG, etc.
- The header is completed with the END keyword and padded out to the record length of 2880 bytes with spaces.
- The image data is written.