THE DIGITIZED SKY SURVEY

Discs 62–102

The Northern Hemisphere

Mean Data Compression Factor: 10

These discs were mastered to ISO 9660 standard, level 1.

1. INTRODUCTION

The Space Telescope Science Institute (ST ScI) digitized Schmidt survey plates covering the entire sky to obtain the image data needed for construction of the *Guide Star Catalog* (GSC) and to pursue a number of research programs. The digitized versions of the plates are of great utility in astronomical research but distribution of the scans has previously been impractical because of the massive volume of data involved (a total of about 600 Gbytes). However, the H-transform wavelet compression technique now makes such a distribution feasible. With funding from NASA Headquarters, compression of 1540 digitized images covering the entire sky began in June 1992. These 41 discs comprise Part II in a series of CD-ROM publications, and contain a complete imaging survey of the northern hemisphere (plate centers $\delta \geq 0°$) constructed from the 1950–55 epoch Palomar Observatory Sky Survey (POSS). These are deep (2400 s–4200 s) 103a-E exposures obtained through a red plexiglass filter and the original corrector. A digitized image of a single short (300 s) IIIa-J exposure of M31, obtained through a GG 495 filter, is also included in this set. The POSS E survey data were not used in the construction of the GSC. We choose the POSS E data for northern hemisphere coverage because its limiting magnitude is comparable with that of the SERC Southern Sky Survey. The digitized images have been compressed by a factor of 10, on average, and are extremely faithful to the original data (*cf.* §8.3). The 41 discs contain a total of 644 compressed, digitized Schmidt images, an astrometric calibration database, and data access software.

Part I in this series contains a complete imaging survey of the southern hemisphere (plate centers $\delta \leq 0°$) constructed largely from the SERC Southern Sky Survey and the SERC J Equatorial extension (see Table III of Lasker *et al.* 1990, hereafter Paper I). These are deep (1800 s–7200 s) IIIa-J exposures obtained through a GG 395 filter, except for 94 short (240 s) V-band exposures mostly at low galactic latitudes ($|b| \leq 15°$) plus 2 plates covering the Large Magellanic Cloud and 2 short (300 s) V-band exposures, each centered on one of the Magellanic Clouds (see Paper I).

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A detailed presentation of the technical and scientific aspects of these compressed data is being prepared (Postman *et al.* 1995); the information contained in this booklet provides a brief summary of the most important issues.

2. THE SCANS

The plates were digitized using the ST ScI scanning microdensitometers, which are described in Paper I. A pixel size of $25\,\mu$m square, with a $50\,\mu$m apodized aperture was used. The pixel data are on a photographic density scale, with density 5 being $2^{15} - 1$, right adjusted in a 16 bit word. Therefore, to convert data values (DN) to photographic density (γ) use the expression

$$\gamma = DN/6553.4.$$

The nominal $25\,\mu$m pixel size is actually $25.284\,\mu$m ($1''\!.70$ at the Schmidt plate scale of $67''\!.2\,\mathrm{mm}^{-1}$), which is a natural unit in the system of the HeNe laser used for positional measurement. However, there are ten POSS E plates (XE203, XE206, XE284, XE509, XE515, XE524, XE541, XE543, XE566, and XE574) that were instead scanned with a pixel size of $24.996\,\mu$m using the refurbished ST ScI microdensitometer, and two SERC J plates (S208 and S516) that were scanned with a rectangular pixel $25.284\,\mu$m $\times$ $25.000\,\mu$m in size.

The northern scans have undergone extensive quality assurance checks. Two artifacts that can be introduced during digitization are chopping (misalignment of odd and even pixels within individual columns) and shearing (misalignment of odd and even scan rows). Algorithms to measure these effects are based on the symmetries of the appropriate correlations. Fourier methods are then used to achieve the necessary repairs. The deshearing is a simple application of the shifting theorem, while dechopping is a special case of the "interlace" problem (Bracewell 1965). Of the 644 scans on discs 62–102, 3 required deshearing and 133 required dechopping. In general, repaired scans are indistinguishable from good scans with small or negligible digitization artifacts. The keywords

`DCHOPPED` and `DSHEARED` in the headers of decompressed images indicate the image repair status.

3. DISC ORGANIZATION

Each disc has a root directory which contains one or more files and several directory trees. In the root directory of all 41 discs is a file identified `COPYRGHT.;1` containing the copyright notice for the disc, and directories identified for each plate on the disc. The latter contain the compressed image data. In addition, in the root directory of disc 102, there is also a file identified `README.TXT;1` containing a copy of this introduction, and the following two additional directories.

`HEADERS` Contains astrometric calibration header files, one for each plate, and other required calibration files.

`SOFTWARE` Contains version 1.1 of the GetImage software for accessing the compressed data. The files identified `GETIMAGE.BCK;1` and `GETIMAGE.TAR;1` are an OpenVMS backup saveset and a UNIX tar file of GetImage, respectively. There is also a directory tree `GETIMAGE` that contains an unpacked version of the software. The top directory of the `GETIMAGE` directory tree contains files to compile and run GetImage under OpenVMS and UNIX systems, and a directory identified `SOURCE` that contains the source files for GetImage.

The contents of the directory tree `GETIMAGE` are discussed in §5. The contents of the directories which contain the compressed data and the calibration files are described in §6.

Each disc has a volume label of the form `USA_AURA_STSI_DSS1_`*nnnn*, where *nnnn* is the right justified, zero filled disc number. The set of discs does not comprise an ISO 9660 volume set.

4. HEADERS

A header file is provided in the directory identified HEADERS on disc 102 for the compressed image data from each of the plates. These header files contain information about each photographic plate and its corresponding digitized image, as well as astrometric calibrations.

The original set of header files provided on disc 61 for the southern plate data is inhomogeneous for historical reasons. We have included a new, homogeneous set of these header files on disc 102, together with header files for the northern plate data. All the header files on disc 102 use the same set of keywords.

When the GetImage software (discussed in §5) extracts an image, the header file for the appropriate plate data is used to construct the header for the extracted image. This header contains additional information such as the data value range of the extracted image, as well as the position of the extracted image relative to the full plate image.

Before installing the new version of GetImage, any original header files copied from disc 61 should be deleted from magnetic disk. They will be superseded by new versions when the header files from disc 102 are installed.

5. SOFTWARE

5.1 The GetImage Program

A new version of the program called GetImage for reading the compressed images is provided in the `SOFTWARE` directory tree on disc 102. This new version, version 1.1, corrects several minor problems associated with version 1.0, and utilizes a new program named ss_mount for handling disc mounting management on a selected variety of UNIX systems. In addition, this version allows the use of a special IRAF/STSDAS task to drive GetImage. See the file identified `GETIMG.TXT;1` for details of the changes to GetImage in version 1.1. Note that the installation instructions in the file identified `install.unx` for UNIX systems have been modified for version 1.1 to accomodate the ss_mount program.

The software is provided in three forms: as a backup saveset for Open-VMS systems (`GETIMAGE.BCK;1`), as a tar file for UNIX systems (`GET-IMAGE.TAR;1`), and in an unpacked form in the directory tree `GETIMAGE`. The backup saveset and tar files include installation instructions for their respective systems. The unpacked form includes the installation instructions for both OpenVMS and UNIX systems. We recommend that the backup saveset or tar file be used to extract the software for the appropriate system. Instructions for unpacking GetImage are given below.

GetImage takes as input the equatorial coordinates for the field center and the rectangular size of the field in arc minutes. The user will be prompted to mount the appropriate disc for the field, if it is not already mounted. The image corresponding to the requested field will then be extracted. The input may be specified either interactively or from a file.

The extracted images can be written as either FITS files (the default) or as GEIS (`hhh/hhd`) images.

GetImage requires about 15 Mbytes of disk space to run. This is because simultaneous access to the plate image headers and the plate image data is required. Thus, the header files must be copied from the `HEADERS` directory on disc 102 to magnetic disk. Procedures for copying the header files are included with the installation instructions provided with the software.

GetImage has been successfully built and run on Digital Equipment Corporation VAX and AXP computers running the OpenVMS operating system, and on Sun Microsystems computers running the SunOS and Solaris UNIX operating systems. The typical time required to extract a $10'$ field is about 5 s on a DEC 3000 M600 workstation with 96 Mbytes of RAM, about 30 s on a DEC VAXstation 3100 with 24 Mbytes of RAM, and about 10 s on a SUN Sparcstation 10 with 32 Mbytes of RAM.

It should be possible to use the software with slight modifications on other machines and other operating systems. In the top directory of the `GETIMAGE` directory tree, the file identified `OSDEPEND.TXT;1` lists the places in the source of GetImage that are operating system dependent. Other system-dependencies may be introduced if the machine uses other than 32-bit integers for C `int` variables.

Future updates to GetImage will be made available via anonymous ftp on the Space Telescope Electronic Information Service (STEIS). To be informed of of new versions of GetImage, send a request containing your e-mail address to `getimage@stsci.edu`.

5.2 Installation on OpenVMS Systems

To install GetImage on OpenVMS systems:

1) Mount disc 102 as appropriate for your system. (See your system manager if you are unsure about how to do this.)

2) Set your default directory to the desired parent directory for Get-Image. (Note: There must be at least 15 Mbytes of free disk space there.)

3) Issue the following `BACKUP` command, where `CDROM` is the device on which disc 102 is mounted:

   `$ BACKUP CDROM:[SOFTWARE]GETIMAGE.BCK/SAVE_SET [...]`

4) Set your default directory to the directory `[.GETIMAGE]` that was created with the `BACKUP` command.

5) Follow the instructions in the file `INSTALL.VMS` to compile Get-Image and copy the plate image header files to magnetic disk.

6) Read the file `README.TXT` for information on how to use GetImage.

5.3 Installation on UNIX Systems

To install GetImage on UNIX systems:

1) Mount disc 102 as appropriate for your system. (See your system manager if you are unsure about how to do this.)

2) Change directory to the desired parent directory for GetImage. (Note: There must be at least 15 Mbytes of free disk space there.)

3) Issue the following `tar` command, where `/cdrom` is the mount point where disc 102 is mounted:

```
% tar -xf /cdrom/software/getimage.tar
```

4) Change directory to the directory `getimage` that was created with the `tar` command.

5) Follow the instructions in the file `install.unx` to compile GetImage and copy the plate image header files to magnetic disk.

6) Read the file `readme.txt` for information on how to use GetImage.

6. THE DATA AND ASTROMETRIC SOLUTIONS

The original plate images are composed of 14000×13999 pixels (or, for the plates scanned with a non-standard pixel size, 14000×14000 pixels). To allow fast access to any portion of the plates, the images were divided into blocks of 500×500 pixels (500×499 for the last row, as appropriate) that were compressed separately. The directories with compressed data therefore contain 784 compressed subimage files identified as *plate*.`00;1`, *plate*.`01;1`, ..., *plate*.`09;1`, *plate*.`0A;1`, ..., *plate*.`0R;1`, *plate*.`10;1`, ..., *plate*.`RR;1`. The GetImage image extraction software allows any arbitrary section of a plate to be extracted; only the blocks that are needed for the requested section are uncompressed.

In the HEADERS directory on disc 102, there are header files for all the plate images contained on discs 1–102. These header files, identified as *plate*.`HHH;1`, are text files containing a FITS-like description of the plate scans. Keywords other than those for standard FITS headers describe the details of the plate scans, including a polynomial solution for mapping X, Y pixel coordinates on the plate to right ascension and declination. The polynomial form of the astrometric solutions is identical to that adopted for the GSC (versions 1.0 and 1.1). The polynomial coefficients were generated using the code described by Russell *et al.* (1990) and astrometric reference positions from the AGK3 catalog. As these are *new* solutions computed for plates distinct from the Palomar Quick V survey used to construct the northern hemisphere sections of the GSC, **the positions of objects measured using the POSS images may disagree with their positions in the GSC reference frame**, even if proper motion is negligible. The size of such discrepancies may be of order $0''\!\!.5$ at the plate center, and somewhat larger near the edges.

To compute an equatorial position (J2000) from pixel coordinates X, Y (computed with respect to the origin of the full 14000×13999 pixel image) one must first convert X, Y to units of mm from the plate center x, y,

$$x = (x_c - p_x X)/1000,$$
$$y = (p_y Y - y_c)/1000,$$

where x_c and y_c are the plate center coordinates in μm (assigned to keywords PP03 and PP06, respectively, in the FITS header) and p_x and p_y are the x and y dimensions of a pixel in μm (assigned to keywords XPIXELSZ and YPIXELSZ, respectively, in the FITS header). One then constructs the standard coordinates ξ, η,

$$\begin{aligned}
\xi = {} & a_1 x + a_2 y + a_3 + a_4 x^2 + a_5 xy + a_6 y^2 \\
& + a_7 (x^2 + y^2) + a_8 x^3 + a_9 x^2 y + a_{10} xy^2 \\
& + a_{11} y^3 + a_{12} x(x^2 + y^2) + a_{13} x(x^2 + y^2)^2, \\
\eta = {} & b_1 y + b_2 x + b_3 + b_4 y^2 + b_5 xy + b_6 x^2 \\
& + b_7 (x^2 + y^2) + b_8 y^3 + b_9 xy^2 + b_{10} x^2 y \\
& + b_{11} x^3 + b_{12} y(x^2 + y^2) + b_{13} y(x^2 + y^2)^2,
\end{aligned}$$

where $a_1, \ldots, a_{13}$ are assigned to keywords AMDX1, ..., AMDX13 and $b_1, \ldots, b_{13}$ are assigned to keywords AMDY1, ..., AMDY13. The keywords AMDX14, ..., AMDX20 and AMDY14, ..., AMDY20 are not currently used. The standard coordinates, as computed above, will be in units of arcseconds. Finally,

the J2000 celestial coordinates α, δ (in radians) are computed from the standard coordinates as follows:

$$\alpha = \arctan\left[\left(\xi / \cos\delta_c\right) / \left(1 - \eta\tan\delta_c\right)\right] + \alpha_c,$$
$$\delta = \arctan\left\{\left[\left(\eta + \tan\delta_c\right)\cos\left(\alpha - \alpha_c\right)\right] / \left[1 - \eta\tan\delta_c\right]\right\},$$

where α_c is the plate center right ascension (assigned to keywords PLTRAH, PLTRAM, and PLTRAS) and δ_c is the plate center declination (assigned to keywords PLTDECSN, PLTDECD, PLTDECM, and PLTDECS). The variables α_c, δ_c, ξ, and η must be converted to radians before using the above expressions! If $\alpha < 0$, one must add 2π to its value to get the correct right ascension.

The origin convention adopted in generating the astrometric solutions is that the X, Y coordinates of the lower left hand corner of the lower left hand pixel in a 14000×13999 pixel image are $(1.0, 1.0)$. Therefore, the center of the lower left hand pixel is $(1.5, 1.5)$. This is contrary to the FITS standard and the expectations of some popular image analysis packages, which define the center coordinates of the origin pixel to be $(1.0, 1.0)$. If using software that expects pixel centers to have integral coordinate values, a $(+0.5, +0.5)$ offset should be added to the measured X, Y coordinates prior to computing celestial coordinates. Failure to do so could result in a $\sim 1\rlap{.}''2$ position error.

One also must assure that any image display software properly sets the absolute values of the origin coordinates for the particular subimage being processed. Some image display packages generate only relative coordinates [ie. the origin is always $(0, 0)$ or $(1, 1)$] and, consequently, gross position errors could be introduced. The proper X, Y coordinates of the lower left

hand corner of the lower left hand pixel for any given subimage are stored in the keywords `CNPIX1` and `CNPIX2`, respectively.

The above information is provided for those who wish to compute object coordinates once a subimage has been uncompressed. We suggest examining the functions `readhr` (found in the file `header.c` of the GetImage software) and `amdpos` (found in the file `astrmcal.c` of the GetImage software) to see how the keywords are used in an actual algorithm. Photometric solutions have not been provided with Parts I or II of the *Digitized Sky Survey*; however, advanced calibrations will be provided in Part III of this series.

7. NETWORK ACCESS POLICY

Users of stand-alone computing systems with *no* remote access capability may access the ST ScI *Digitized Sky Survey* CD-ROMs without a license as long as they note and comply fully with the copyright limitations given in this booklet and in the image header files. For the purposes of this policy, remote access is defined as any method of electronic data transfer which allows these data to be copied from the host machine to remote nodes. Such methods include, but are not restricted to, serial lines, local area and wide area networks.

Users wishing to provide remote access to these data may do so as long as they (1) note and comply fully with the copyright limitations stated in this booklet and in the image header files, *and* (2) obtain an appropriate license by contacting:

> Office of Contract & Business Services
> Attn: Digitized Sky Survey
> Space Telescope Science Institute
> 3700 San Martin Drive
> Baltimore, MD 21218
> U. S. A.

The license agreement for non-profit users will place specifications on the identification of the data and its sources and there will be no additional fees. A limited period of time will be specified in the license agreement during which unrestricted public access to the data contained on these CD-ROMs will be prohibited.

All users of these data are asked to acknowledge both the original data sources (given in the image headers) and the ST ScI digitization and compression.

8. IMAGE COMPRESSION

8.1 The H-transform

The image compression technique we are using is based on the H-transform (Fritze *et al.* 1977; see also Richter 1978 and Capaccioli *et al.* 1988). The H-transform is a two-dimensional generalization of the Haar transform (Haar 1910). The H-transform is calculated for an image of size $2^N \times 2^N$ as follows:

- Divide the image up into blocks of 2×2 pixels. Call the 4 pixels in a block a_{00}, a_{10}, a_{01}, and a_{11}.
- For each block compute 4 coefficients:

$$h_0 = (a_{11} + a_{10} + a_{01} + a_{00})/2,$$
$$h_x = (a_{11} + a_{10} - a_{01} - a_{00})/2,$$
$$h_y = (a_{11} - a_{10} + a_{01} - a_{00})/2,$$
$$h_c = (a_{11} - a_{10} - a_{01} + a_{00})/2.$$

- Construct a $2^{N-1} \times 2^{N-1}$ image from the h_0 values for each 2×2 block. Divide that image up into 2×2 blocks and repeat the above calculation. Repeat this process N times, reducing the image in size by a factor of 2 at each step, until only one h_0 value remains.

This calculation can be inverted easily to recover the original image from its transform. The transform is exactly reversible using integer arithmetic if one does not divide by 2 for the first set of coefficients. The extension of the definition of the transform so that it can be computed for non-square

images that do not have sides which are powers of 2 is straightforward. The H-transform can be performed in place in memory and is very fast to compute, requiring only about $4M^2$ (integer) additions for a $M \times M$ image.

If the image is nearly noiseless, the H-transform is somewhat easier to compress than the original image because the differences of adjacent pixels (as computed in the H-transform) tend to be smaller than the original pixel values for smooth images. Consequently, fewer bits are required to store the values of the H-transform coefficients than are required for the original image. For very smooth images the pixel values may be constant over large regions, leading to transform coefficients which are zero over large areas.

Noisy images still do not compress well when transformed, though. Suppose there is noise σ in each pixel of the original image. Then from simple propagation of errors, the noise in each of the H-transform coefficients is also σ. To compress noisy images, divide each coefficient by $S\sigma$, where $S \sim 1$ is chosen according to how much loss is acceptable. This reduces the noise in the transform to $0.5/S$, so that large portions of the transform are zero (or nearly zero) and the transform is highly compressible.

Why is this better than simply thresholding the original image? If we simply divide the image by σ then we lose all information on objects that are within 1σ of sky in a single pixel, but that are detectable by averaging a block of pixels. On the other hand, in dividing the H-transform by σ, we preserve the information on any object that is detectable by summing a block of pixels! The quantized H-transform preserves the mean of the image for every block of pixels having a mean significantly different than that of neighboring blocks of pixels.

8.2 Coding the H-transform

The quantized H-transform has a rather peculiar structure. Not only are large areas of the transform image zero, but the non-zero values are concentrated strongly in the lower-order coefficients. The best approach we have found to code the coefficient values efficiently is quadtree coding of each bitplane of the transform array. Quadtree coding has been used for many purposes (see Samet 1984 for a review); the particular form we are using was suggested by Huang and Bijaoui (1991) for image compression.

- Divide the bitplane up into 4 quadrants. For each quadrant code a '1' if there are any 1-bits in the quadrant, else code a '0'.

- Subdivide each quadrant which is not all zero into 4 more pieces and code them similarly. Continue until one is down to the level of individual pixels.

This coding (which Huang and Bijaoui call "hierarchic 4-bit one" coding) is obviously very well suited to the H-transform image because successively lower orders of the H-transform coefficients are located in successively divided quadrants of the image.

We follow the quadtree coding with a fixed Huffman coding that uses 3 bits for quadtree values which are common (*eg.* 0001, 0010, 0100, and 1000) and uses 4 or 5 bits for less common values. This reduces the final compressed file size by about 10% at little computational cost. Slightly better compression can be achieved by following quadtree coding with arithmetic coding (Witten, Neal, and Cleary 1987), but the CPU costs of arithmetic coding are not, in our view, justified for 3–4% better compression.

For completely random bitplanes, quadtree coding can actually use more storage than simply writing the bitplane directly; in that case we just dump the bitplane with no coding.

8.3 Astrometric and Photometric Properties of Compressed Images

We have conducted experiments to study the degradation of astrometry and photometry on the compressed images compared to the original images (White, Postman, and Lattanzi 1992). Even the most highly compressed images have very good photometric properties for both point sources and extended sources; indeed, photometry of extended objects can be improved by the adaptive filtering of the H-transform (Cappacioli *et al.* 1988). Astrometry is hardly affected by the compression for modest compression factors (up to about a factor of 20 for our digitized Schmidt plates), but does begin to degrade for images with higher compression factors.

9. ACKNOWLEDGMENTS

10. REFERENCES

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