674-SO-43, Version 4.6,
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SIRTF Science Center

Downlink Segment

Subsystem Design Specification

AOT Products Subsystem: MIRRORSYNCH

21 April 2005

California Institute of Technology
SIRTF Science Center

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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SIRTF Science Center

Subsystem Design Specification

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1 Revision History

Version	Description	Date
1.0	Initial version	June 28, 2002
2.0	Modified the algorithm to account for the DCENUM keyword starting at zero.	July 29, 2002
2.1	Modified algorithm to read the new scan mirror mode keyword CSM_MOD which was previously defined as SM_MODE. The value for CSM_MOD can be either 0 (“chop”) or 1 (“scan”).	September 28, 2002
3.0	Complete re-write of algorithm as presented in Instrument Team’s MIPS scan-mirror emulator software. Also, print out to standard output more diagnostic scan-mirror parameters.	November 2, 2002
3.1	Changed use of conversion factor in algorithm (Sky_Scan_Rate_Conversion_Factor) to allow for input sky-scan rate to be in default units of milli-arcsec/sec and computed axle rate in deg/milli-sec.	March 11, 2003
3.8	Converted DAC_to_DEG_conv_factor_coarse namelist/command-line parameter to a hard-coded non-linear (quadratic) model which depends on effective DAC value. This latter model will be used if DAC_to_DEG_conv_factor_coarse is unspecified or set to zero as input.	March 27, 2003
4.0	Made copying of table headers from input pointing history file to output pointing history file (containing mirror angle) more generic so can account for cases when input pointing history is from a concatenation of two separate BPHF’s whose boundary falls within the time span of a DCE.	May 5, 2003
4.5	• Allow option to read in scan-mirror angle about axis (in degrees and DAC) directly from command-line instead of computing	December 7, 2003

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	from first principles. • Use two methods to compute scan-mirror deflection angle (and uncertainties) on sky: Instrument Team (IT) method and Focal Plane Survey (FPS) method. • Allow specification of <u>all</u> aperture-name dependent mirror parameters in a control table: "mirrorparameters.tbl"	
4.6	Added functionality to use relative "spot" positions measured from the mips24 FPA at a fixed mirror position to correct for the scan-mirror wobble and hence derived pointing (for all MIPS arrays) downstream. The new parameter is defined by the "YspotPosDiff" field in the mrrorparameters.tbl calibration file.	April 21, 2005

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List of Tables

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1. Introduction

1.1. Purpose and Scope

The Subsystem Design Specification is a document that describes the basic requirements, assumptions, definitions, software-design details and necessary interfaces for each subsystem. The document will be used to trace the incremental development of each subsystem and also to allow trace-back of levied requirements; this document should have sufficient detail to allow future modification or maintenance of the software by developers other than the original developers. This document is an evolving document as changes may occur in the course of science instrument hardware design and maturity of operational procedures. This document is not intended to repeat sections or chapters from other Project documents; when appropriate, references to proper sections of primary reference documents will be made.

1.2. Document Organization

This document is organized along the major themes of Requirements; Assumptions; Operational Concept; Functional Descriptions; Functional Dependencies; Input; Output; Other S/S Interfaces; Algorithm Descriptions (when applicable); and Major Liens.

The material contained in this document represent the current understanding of the capabilities of the major SIRTF systems. Areas that require further analysis are noted by TBD (To Be Determined) or TBR (To Be Resolved). TBD indicates missing data that are not yet available. TBR indicates preliminary data that are not firmly established and are subject to change.

1.3. Relationship to Other Documents

The requirements on the operation of SIRTF flow down from the Science Requirements Document (674-SN-100) and the Facility Requirements Document (674-FE-100). The Science Operations System is governed by the SOS Requirements Document (674-SO-100). The current document is also cognizant of the requirements that appear in the Observatory Performance and Interface Control Document (674-SEIT-100) as well as the Flight Ground Interface Control Document (674-FE-101). This document is also affected by the FOS/SOS Interface Control Document (674-FE-102) that governs interfaces between the Flight Operations System and the Science Operations System. Related Software Interface Specifications (SIS) will be as indicated in Section 2.2 of this document.

1.4. Change Procedure

This document is a level 4 document according to the SIRTF Project Documentation Plan (674-FE-103). Changes to this document after approval require the approval of the SOS Change Board (TBD). The process for change control is described in the SOS Configuration Management Plan.

2. Overview

MIRRORSYNCH reads pointing data from a "Boresight-Pointing History File" (BPHF) for the time span of a single DCE and scan-mirror parameters for a partilcular FOV and computes the scan-mirror deflection angle at each sampled pointing-time. The scan-mirror positions are synchronized to the boresight pointing. This information will be used downstream to perform the boresight-to-array pointing transfer and specifically applies to the MIPS instrument on board SIRTF.

MIRRORSYNCH requires as input: a standard FITS image, a boresight-pointing history file generated by the **getPH** software upstream, parameters specifying the mirror configuration at the start time of a DCE and for a "scan-mode" observation, the mirror scan rate. The main output is a "mirror-pointing history file" (MPHF) in IPAC table format containing mirror sky deflection angles as a function of pointing sampling time. In addition, the MPHF contains entries from the BPHF. MIRRORSYNCH is written in standard ANSI/ISO C.

2.1. MIRRORSYNCH Requirements

MIRRORSYNCH is initiated by a startup script under the control of the pipeline executive and does its required functions for a given DCE image or pre-processed DCE image; this involves performing the following tasks.

A.) Retrieve the command line parameters passed by the start up script and use them to run the program.

B.) Read in as input a standard FITS image, a "boresight-pointing history file" (BPHF) and mirror parameters.

C.) Produce as primary output a "mirror-pointing history file" (MPHF).

D.) Provide exit codes to the pipeline executive and also provides logon and logoff messages identifying the version number and write any error messages to the standard output devices.

E.) Produce a processing summary.

2.2. Applicable Documents

The following documents are relevant to the MIRRORSYNCH program of the AOT PRODUCTS Subsystems.

A.) The SOS Requirements Document

B.) The SOS Downlink Requirements Document

C.) The SOS Downlink Software Development Guidelines

D.) The following Software Interface Specifications (SIS)

SOSDL-SIS-PT-3000 (pointing transfer design)

SFO-SIS-3030 (boresight-pointing history file format and units)

2.3. Version History

2.3.1. Version 1.0

Initial version created on June 28, 2002.

2.3.2. Version 2.0

This version now assumes DCENUM starts at 0. Previously it started at 1.

2.3.3. Version 2.1

Following the change to CTD version 2.8.0, the scan mirror mode keyword (initially SM_MODE) has been redefined to CSM_MOD. Furthermore, this keyword now assumes the two values 0 (for chopping) or 1 (for scan).

2.3.4. Version 3.0

Algorithm was revised, using the method presented in the Instrument Team's scan-mirror emulator software. More diagnostic parameters are printed to standard output.

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2.3.5. Version 3.1

Changed use of conversion factor in algorithm (Sky_Scan_Rate_Conversion_Factor) to allow for input sky-scan rate to be in default units of milli-arcsec/sec and computed axle rate in deg/milli-sec.

2.3.6. Version 3.8

Converted DAC_to_DEG_conv_factor_coarse namelist/command-line parameter to a hard-coded non-linear (quadratic) model which depends on effective DAC value. This latter model will be used if DAC_to_DEG_conv_factor_coarse is unspecified or set to zero as input.

2.3.7. Version 4.0

Made copying of table headers from input pointing history file to output pointing history file (containing mirror angle) more generic so can account for cases when input pointing history is from a concatenation of two separate BPHF's whose boundary falls within the time span of a DCE.

2.3.8. Version 4.5

- Allow option to read in scan-mirror angle about axis (in degrees and DAC) directly from command-line instead of computing from first principles.
- Use two methods to compute scan-mirror deflection angle (and uncertainties) on sky: Instrument Team (IT) method and Focal Plane Survey (FPS) method.
- Allow specification of all aperture-name dependent mirror parameters in a control table: "mirrorparameters.tbl"

2.3.9. Version 4.6

Added functionality to use relative "spot" positions measured from the mips24 FPA at a fixed mirror position to correct for the scan-mirror wobble and hence derived pointing (for all MIPS arrays) downstream. The new parameter is defined by the "YspotPosDiff" field in the mrrorparameters.tbl calibration file.

2.4. Liens

No liens have been identified.

3. Input

3.1. MIRRORSYNCH Input

MIRRORSYNCH takes all of its input from either the command line or namelist file, which is set up by the startup script that is controlled by the pipeline executive or standalone. If the namelist is not specified, then all required inputs are expected from the command line. If both namelist and command-line inputs are specified, then the command-line inputs override the namelist values. Prior to reading namelist and/or command-line parameters, default values for the relevant parameters are assigned.

3.1.1. MIRRORSYNCH NAMELIST Input

MIRRORSYNCH reads the NAMELIST file whose name is passed to it by start-up script. The name of the NAMELIST is PRESATIN. The parameters that can be defined in the NAMELIST are listed in Table 1.

Namelist variable	**Description**	**Dim.**	**Type**	**Units**	**Default**
FITS_Image_Filename	Required FITS-image filename.	256	C	-	Null
Boresight_Ptg_History_File	Optional BPHF name in IPAC table format.	256	C	-	Null
Output_Mirror_History_File	Optional MPHF name for output (otherwise, FITS header always updated).	256	C	-	Null
Input_Mirror_Parameters_File	Required mirror parameters file	256	C	-	Null

Aperture_Name_of_Interest	Required aperture name to select from mirror parameters file	80	C	-	Null
Stimcycle	Optional stim-cycle number. Range allowed: 1 ≤ value ≤ 63	1	I*2	-	Null
Mirror_scanpos1	Optional mirror position from coarse adjustment 1.	1	I*2	DAC	Null
Mirror_scanpos2	Optional mirror position from coarse adjustment 2.	1	I*2	DAC	Null
Mirror_relpos1	Optional mirror position from fine adjustment 1.	1	I*2	DAC	Null
Mirror_relpos2	Optional mirror position from fine adjustment 2.	1	I*2	DAC	Null
Mirror_stepoffset	Optional mirror stepoffset	1	I*2	DAC	Null
Mirror_Sky_Scan_Rate	Required mirror scan rate on sky.	1	R*4	milli-arcsec/sec	Null
Mirror_rampdir	Required ramp-direction flag: value = 0(REV) or 1(FWD).	1	I*2	-	Null
Mirror_start_axis_angle	Optional start mirror axis angle pre-computed from above parameters.	1	R*4	deg	Null
Mirror_start_axis_DAC	Optional effective DAC position corresponding to Mirror_start_axis_angle	1	R*4	DAC	Null
Log_Filename	Optional output log filename	256	C	-	stdout
Ancillary_File_Path	Optional pathname where supporting source files are	256	C	-	./

	installed.				

Table 1. Namelist Parameters

*****NOTE:** The following six parameters are optional: **Stimcycle; Mirror_scanpos1; Mirror_scanpos2; Mirror_relpos1; Mirror_relpos2; Mirror_stepoffset.** If not all of these are specified, then "**Mirror_start_axis_angle**" and "**Mirror_start_axis_DAC**" must be specified.

The following is an example of the contents of a "MIRRORSYNCHIN" NAMELIST file that might be used, where the values specified are not necessarily realistic.

```
 &MIRRORSYNCHIN
  Comment = 'Generic namelist file for mirrorsynch, default values.',
  Ancillary_File_Path = '../mirrorsynch_v4',
  Comment = 'Always Required:',
  FITS_Image_Filename = './testing/test_scan.fits',
  Boresight_Ptg_History_File = './testing/ptghistory.dat',
  Output_Mirror_History_File = './testing/mirrorhistory.dat',
  Comment = 'Always Required:',
  Input_Mirror_Parameters_File = './testing/mirrorparameters.tbl',
  Comment = 'Always Required:',
  Aperture_Name_of_Interest = 'MIPS_24um_center',
  Comment = 'First six parameters below are optional. If not all specified,
then "Mirror_start_axis_angle" and "Mirror_start_axis_DAC" must be
specified.',
  Stimcycle = 25,
  Mirror_scanpos1 = 2007,
  Mirror_scanpos2 = 2007,
  Mirror_relpos1 = 2048,
  Mirror_relpos2 = 1827,
  Mirror_stepoffset = 18,
  Comment = 'Following is in units of degrees; only used if specified',
  xxMirror_start_axis_angle = 0.003018,
  Comment = 'Following is in units of degrees; only used if specified',
  xxMirror_start_axis_DAC = 1000,
  Comment = 'Always Required, in units of milli-arcsec / sec on sky',
  Mirror_Sky_Scan_Rate = 6520.00,
  Comment = 'Always Required, = 0(REV) or 1(FWD)',
  Mirror_rampdir = 1,
  Log_Filename = 'stdout',
 &END
```

3.1.2. MIRRORSYNCH Command-Line Input

Alternatively, all inputs can be specified via command line, in which case, a namelist file is not needed. Or, inputs can be provided with a hybrid of both namelist and command-line mechanisms, with the latter over-riding the former. Table 2 lists the available command-line options associated with their namelist-variable counterparts, as well as other options for specifying the namelist-file name and making the standard output more verbose.

3.1.3. MIRRORSYNCH FITS Input

MIRRORSYNCH uses the FITSIO library routines to read in the FITS-formatted input data file. The routines used are: fits_open_file, fits_read_keys_lng, fits_read_keys_dbl, fits_read_img, and fits_close_file.

Command-line option	Variable
-n	Namelist_Filename
-i1	FITS_Image_Filename
-i2	Boresight_Ptg_History_File
-i3	Input_Mirror_Parameters_File
-o	Output_Mirror_History_File
-c0	Mirror_start_axis_DAC
-c1	Mirror_start_axis_angle
-c4	Stimcycle
-c5	Aperture_Name_of_Interest
-m1	Mirror_scanpos1
-m2	Mirror_scanpos2

-m3	Mirror_relpos1
-m4	Mirror_relpos2
-m5	Mirror_stepoffset
-m6	Mirror_Sky_Scan_Rate
-m9	Mirror_rampdir
-l	Log_Filename
-a	Ancillary_File_Path
-v (verbose switch)	-
-vv (super-verbose switch)	-

Table 2. Command-line options

4. Processing

4.1. MIRRORSYNCH Processing

MIRRORSYNCH begins processing by writing its name and version number to standard output (verbose mode only), and then it initializes relevant variables with defaults values, and checks that the required namelist parameters and/or command-line parameters were passed to it. If this condition is not true, then it writes a message stating which parameters are missing, recommends a look at this document, and terminates by issuing an appropriate exit code to the pipeline executive; otherwise it proceeds as follows.

If an error occurs during processing, then an error message is written to standard output, a termination-status code is written to the log file, and an exit code to the pipeline executive issued.

After processing, the program name and version number, namelist filename (if used), input, and output filenames, values of other input parameters, date and time, processing time, and a termination-status code are written a log file.

4.2 MIRRORSYNCH Processing Phases

MIRRORSYNCH operates in nine phases: initialization, FITS keyword data and mirror parameters input, boresight-pointing history file input (optional), computation of mirror-position at DCE start time, mirror-wobble correction, computation of mirror positions at pointing times, uncertainty estimation, results output, and termination. This processing level is depicted in Figure 1.

4.2.1. MIRRORSYNCH Initialization

MIRRORSYNCH initializes itself by performing the following tasks.

A.) A message is printed to STDOUT (verbose mode only), which includes the program name and version number.

B.) If specified on the command line, the NAMELIST file is opened and read. If any errors are encountered, a message is printed, and execution aborts.

C.) The remaining command-line inputs are read and checked for correct data range, consistency, etc. If any errors are encountered, a message is printed, and execution aborts.

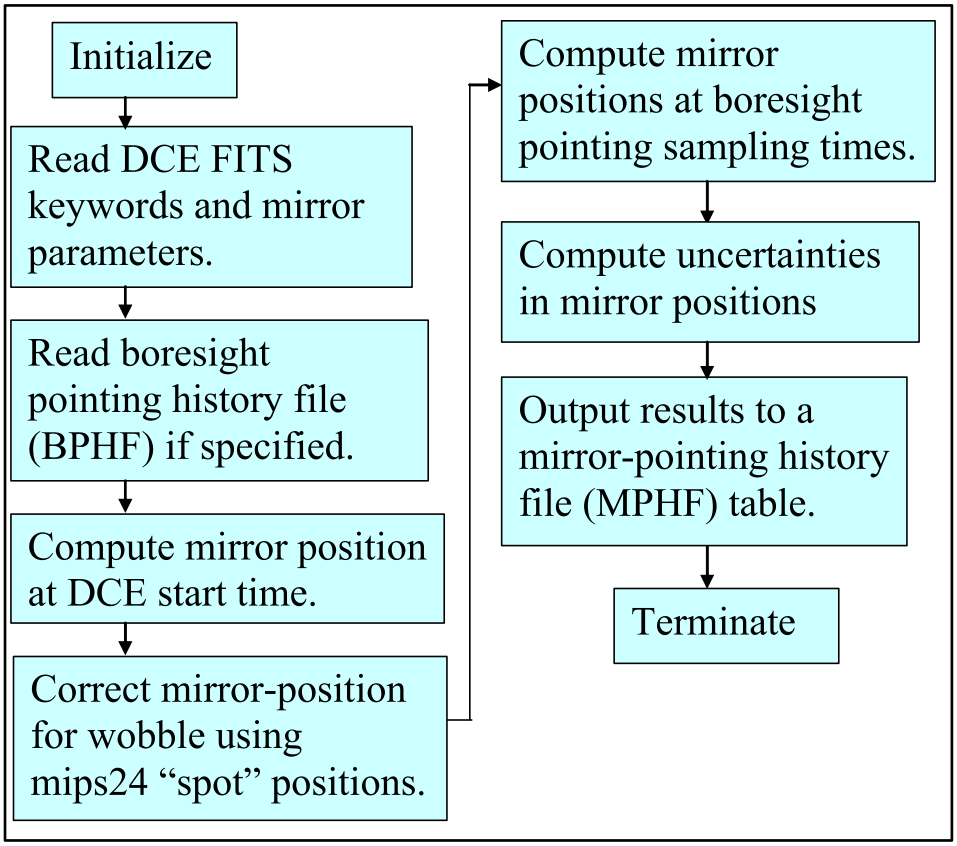

Figure 1. MIRRORSYNCH data and processing flow

4.2.2. FITS Data and Mirror Parameters Input

The FITS header of a DCE image (namelist parameter: FITS_Image_Filename) is read and stored in memory. The keywords read from the header are “INSTRUME”, “CSM_MOD” (or its equivalent as specified in the include file mirrorsynch.h). “DCENUM” and “SCLK_OBS”. “INSTRUME” specifies the instrument name (in this case MIPS) and “CSM_MOD” specifies the scan-mirror mode which can be either “chop” (specified by value 0) or “scan” (value 1). Both these keywords are checked that their values are set appropriately and if not, the program

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will about with a message sent to standard output. An additional parameter expected in the FITS header is "DCENUM". This specifies the DCE number in an exposure and is used for computing the mirror position (see below). "SCLK_OBS" represents the sync-pule time or effectively, the start-time integration for a DCE.

All configuration parameters for the specified aperture-name of interest (namelist parameter: "Aperture_Name_of_Interest") are read from a file specified by "Input_Mirror_Parameters_File". This file is a table in IPAC format and contains all the scan-mirror parameters necessary to compute the mirror position as a function of pointing history sample time. An example is as follows:

```
\char Mirror parameters for pointing transfer
\char FOV_name = Field of view identifier for the appropriate mode
\char ZP_Coarse = Coarse mirror DAC position of optical Zero Point
\char ZP_Fine = Fine mirror DAC position of optical Zero Point
\char beta_IT = Instrument Team dimensionless scale factor: mirr-angle/sky-angle
\char sigma_beta_IT = associated uncertainty in beta_IT
\char beta_fps = mirror-angle scale factor from Focal Plane Survey
\char sigma_beta_fps = relative uncertainty in beta_fps
\char am1 = component one of mirror axis unit vector
\char am2 = component two of mirror axis unit vector
\char am3 = component three of mirror axis unit vector
\char In practice, am3 = (+/-)sqrt(1.0 - am1*am1 - am2*am2)
\char sigma_am1 = uncertainty in am1
\char sigma_am2 = uncertainty in am2
\char Method = 1 for Instrument Team model involving F(DAC) below
\char Method = 2 for model with beta_fps = constant for that mode
\char Following are coefficients of quadratic model representing
\char F(DAC) = Coeff1 + Coeff2*DAC + Coeff3*DAC**2 (arcsec-about-axis/DAC)
\real Coeff1 = 2.619e+01
\real Coeff2 = -8.828e-03
\real Coeff3 = 2.213e-06
\real sig_Coeff1 = 6.0e-01
\real sig_Coeff2 = 6.0e-05
\real sig_Coeff3 = 6.0e-08
\real cov_Coeff12 = 0.0
\real cov_Coeff13 = 0.0
\real cov_Coeff23 = 0.0
\char Above cov_ terms are defined as the sqrt of the absolute
\char value of the covariance with the sign of the covariance attached.
\char MirrTimeOffset = SCLK_OBS(of DCE) - SCLK_MIRROR(unknown)
\char Following represents difference: Yspot_pos(obs) - Y_spot_pos(true) in
\char mips24 FPA in arcsec at fixed mirror position. Only used with Method=2:
\real YspotPosDiff = 0.00
\
| FOV_Name          | ZP_Coarse | ZP_Fine  | beta_IT  | sigma_beta_IT | beta_fps         |
sigma_beta_fps | am1      | am2            | am3            | sigma_am1 | sigma_am2 | Method |
MirrTimeOffset |
| char              | int       | int      | double   | double        | double           | double
| double    | double         | double         | double    | double    | int    | double          |
| null              | DAC       | DAC      | null     | null          | sky-radian/DAC   | sky-
radian/DAC | null     | null           | null           | null      | null      | null   |
seconds        |
```


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```
  MIPS_24um           2007         2048       32.635      1.000000        2.7011009289e-06
1.000e-08        0.000000   0.012500125117   0.999921868686    0.0001       0.0001       2
0.765
  MIPS_70um_center    2007         2048       32.635      1.000000        2.7390903579e-06
5.581e-09        0.000000   0.025434244230   0.999676497283    0.0001       0.0001       2
0.765
  MIPS_70um_fine       875         2048       32.635      1.000000        2.9377920853e-06
1.038e-08        0.000000  -0.074247630835   0.997239835403    0.0001       0.0001       2
0.765
  MIPS_160um          2007         2048       32.635      1.000000        2.7390905936e-06
1.000e-08        0.000000  -0.030274296970   0.999541628419    0.0001       0.0001       2
0.765
  MIPS_SED            3220         2048       32.635      1.000000        2.8649284734e-06
5.136e-08        0.000000   0.046418061449   0.998922100852    0.0001       0.0001       2
0.765
```

The variable scan-mirror parameters are read from either a namelist or command-line and are as follows: **Stimcycle; Mirror_scanpos1; Mirror_scanpos2; Mirror_relpos1; Mirror_relpos2; Mirror_stepoffset.** If not all of these are specified, then "**Mirror_start_axis_angle**" and "**Mirror_start_axis_DAC**" must be specified. These latter two parameters are assumed to be computed upstream.

4.2.3. Boresight-Pointing History File Input

The pointing-history table pertaining to the integration time-span of the DCE is read from the namelist or command line. This is generated upstream using the **getPH** software from a much larger pointing-history file spanning approximately 12 hours of down-linked DCE data. The BPHF is in standard IPAC table format (see example below). The data relevant to this software are in column 1: the pointing times pertaining to the boresight are in milli-seconds with 2-Hz sampling.

```
\character comment = Output from getPH, version 2.0
\character Date-Time = Tue Oct 29 11:16:37 2002
\int SCLKBGN = 734572800
\int SCLKEND = 734616000
\character comment = alpha means R.A in boresight
\character comment = delta means Dec in boresight
\character comment = gamma means twist angle in boresight
\character comment = valpha means variance in alpha
\character comment = vdelta means variance in delta
\character comment = valphadelta means co-variance in alpha and delta
\character comment = vgamma means variance in gamma
\character comment = delta_y means change in the +Y direction
\character comment = delta_z means change in the +Z direction
|time    |alpha     |delta     |gamma     |valpha    |vdelta    |valphadelta|vgamma     |delta_y   |delta_z   |
|int     |double    |double    |double    |double    |doiuble   |double     |double     |double    |double    |
|msec    |degree    |degree    |degree    |arcsec    |arcsec    |arcsec     |arcsec     |arcsec    |arcsec    |
 1746000 304.621178 -95.292878 303.967712 105.959999 105.959999 -138.639999 3435.919922 -12.594000 -90.101997
 1746500 304.467956 -95.368711 303.808411 105.809998 105.809998 -138.789993 3434.389893 -12.549000 -90.021004
 1747000 303.946622 -95.626800 303.266388 105.260002 105.260002 -139.279999 3429.199951 -12.522000 -89.973000
 1747500 303.657644 -95.769867 302.966003 104.959999 104.959999 -139.550003 3426.330078 -12.519000 -89.968002
 1748000 304.067511 -95.566967 303.392212 105.389999 105.389999 -139.160004 3430.409912 -12.519000 -89.968002
 1748500 303.237267 -95.977967 302.528992 104.529999 104.529999 -139.940002 3422.149902 -12.571000 -90.059998
 1749000 303.705911 -95.745978 303.016205 105.010002 105.010002 -139.500000 3426.810059 -12.543000 -90.011002
```

```
1749500 303.489022 -95.853333 302.790710 104.790001 104.790001 -139.710007 3424.649902 -12.505000 -89.942001
1750000 303.552111 -95.822111 302.856293 104.849998 104.849998 -139.649994 3425.280029 -12.503000 -89.939003
1750500 303.976600 -95.611956 303.297607 105.290001 105.290001 -139.250000 3429.500000 -12.424000 -89.796997
1751000 303.619333 -95.788833 302.926208 104.919998 104.919998 -139.580002 3425.949951 -12.411000 -89.773003
```

~
~
~

4.2.4. Mirror Position at DCE "Start-Time"

The algorithm to compute the mirror position at (or close to) the observation start-time of a DCE was taken from C. Englebracht's perl code (dated Aug. 21 2003) and the "MIPS AOR Expansion Test Document" (Ball-Aerospace: March 13-17 2000).

If either the parameters: "Mirror_start_axis_DAC" or "Mirror_start_axis_angle" are not specified on input, then the six variable parameters (see last paragraph section 4.2.2) must be specified. When these six parameters are specified, the mirror axis-angle at the start of a DCE in encoder (DAC) and degree units is computed using the following algorithm:

In DAC units about axis:

```
if scanpos2 = 0 then
   scanpos2 = scanpos1;

cyclepos = fmod(dcenum, Stimcycle);

if cyclepos odd,
scanMirrorDAC = scanpos2+((relpos2+stepoffset*(cyclepos+1) - ZP_Fine)/8.0)

else if cyclepos even,
scanMirrorDAC = scanpos1+((relpos1+stepoffset*(cyclepos+1) - ZP_Fine)/8.0)

where ZP_Fine is from cdf mirrorparameters.tbl,
      scanpos1, relpos1, scanpos2, relpos2, stepoffset and
      Stimcycle are from exposures table, dcenum from dces table.

The appropriate row from  mirrorparameters.tbl is selected
according to the "desired" FOV for pointing reconstruction.
```

In DAC units about axis from optical zero point:

```
theta_t0_DAC  =  ZP_Coarse  – scanMirrorDAC
```

In degree units about axis from optical zero:

THIS IS A PRELIMINARY DOCUMENT, the module described here may or may not be utilized in the final pipelines as described.

```
First compute following quantity:

DAC_to_DEG_conv = (Coeff1 + Coeff2 * scanMirrorDAC +
                   Coeff3*pow(scanMirrorDAC,2))/3600.0;

scanMirrorAxisAngleDegrees = theta_t0_DAC * DAC_to_DEG_conv;

where theta_t0_DAC is from above and Coeff1, Coeff2,
      Coeff3, ZP_Coarse are from mirrorparameters.tbl
```

When the six relevant mirror parameters are not available on input, the parameters "Mirror_start_axis_DAC" and "Mirror_start_axis_angle" must be specified. These are respectively the quantities **scanMirrorDAC** and **scanMirrorAxisAngleDegrees** above.

The mirror position on the sky relative to the optical zero position is computed using two different models defined by different parameterizations for the scan-mirror scale factor in the mirror-parameters configuration table: beta_IT and beta_FPS. These refer to respectively the Instrument Team (IT) and the Focal Plane Survey (FPS) models.

In arcsec units on sky using IT model:

StartposSKY_IT = beta_actual_IT * scanMirrorAxisAngleDegrees * 3600

where beta_actual_IT = (1 / beta_IT) and beta_IT is from the mirrorparameters.tbl file.

In arcsec units on sky using FPS model:

StartposSKY_FPS = beta_FPS * theta_t0_DAC * (180/π) * 3600

4.2.5. Correcting for "Mirror-wobble"

The scan-mirror is known to wobble on-board by up to 3 DAC units, i.e., it does not perform as expected from the scan-mirror model used to predict the nominal mirror positions, **scanMirrorDAC** (or CSM_PRED). This wobble causes the final reconstructed pointing to be off by up to 2 arcsec (or ¾ of a 24µm pixel.). To correct for this, we use a calibration determined from the relative positions of dark spots on the 24µm array. These spots are due to debris on a pick-off mirror in the scan-mirror mechanism. The idea of using these spots as a calibration is illustrated in Figure 2.

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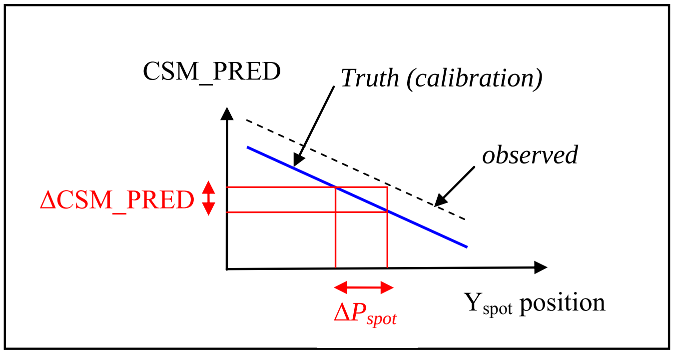

Figure 2. Schematic of CSM_PRED versus mips24 spot "Y" position for computing mirror wobble correction

The procedure to determine the offset correction in CSM_PRED is as follows. First, we measure the Y position (centroid) of a spot for a fixed CSM_PRED from a campaign which we know a-priori has the best *absolute* pointing. We are only interested in the Y position because the scan-mirror motion results in a Y motion of sources on the array. Let us call this position $Y_{spot}(truth)$. This is our "calibrator" position (solid blue line in Figure 2). Then, for some other arbitrary campaign where the mirror may be offset, we measure the position of the same spot at the same CSM_PRED. Let us call this position $Y_{spot}(obs)$. The relative offset in arcsec between these spot positions is then given by:

$$\Delta P_{spot} = S\left[Y_{spot}(obs) - Y_{spot}(truth)\right] \text{ arcsec,}$$

where S = pixel scale in arcsec/pixel units. This offset is equivalent to an offset in pointing projected on the sky and this is specified by the calibration parameter: "**YspotPosDiff**" in the "Input_Mirror_Parameters_File" for MIRRORSYNCH. Therefore, the user is required to specify this parameter for the campaign/data-set of interest so that it can be picked up by subsequent reprocessing. The pointing will then be "corrected" in this reprocessing. The relative spot offset, ΔP_{spot}, can be related to the corresponding offset in mirror position ΔCSM_PRED using the relation for **StartposSKY_FPS** above. Taking the derivative of this with respect to **scanMirrorDAC** (CSM_PRED), we have:

$$\Delta \text{CSM\_PRED} = -\frac{\pi}{180}\frac{1}{3600}\frac{1}{\beta_{fps}}\Delta P_{spot} \quad \text{DAC,}$$

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where β_{fps} is the same as "beta_FPS" above and is dependent on the FOV or mode of the MIPS instrument. Due to its simplicity, this functionality is only available for the Focal Plane Survey (FPS) model, i.e., "Method=2" in the "Input_Mirror_Parameters_File". This relationship is apparent in Figure 2 where a shift in spot (or sky) position at a given scan-mirror position is equivalent to an offset in CSM_PRED in the opposite direction. The MIRRORSYNCH program then internally resets the nominal CSM_PRED (mirror position at start of DCE) according to:

$$\text{CSM\_PRED}(\mathit{true}) = \text{CSM\_PRED}(\text{nominal}) + \Delta\text{CSM\_PRED}.$$

This new (corrected) CSM_PRED is what is propagated downstream for pointing reconstruction purposes.

4.2.6. Mirror Sky Positions at Boresight-Pointing Times

For **"scan" mode** observations, we first convert the input scan-rate (in milli-arcsec/sec) to the required units for use in the IT and FPS models:

R_IT = r * Mirror_Sky_Scan_Rate / (beta_actual_IT * 3.6e+09) **deg./msec about axis**.

R_FPS = r * Mirror_Sky_Scan_Rate / 1.0e+06 **arcsec/msec on sky**.

where r is the mirror-ramp direction flag:

$$r = 1 \Rightarrow \text{Foward Direction (if Mirror\_rampdir} = 1)$$
$$r = -1 \Rightarrow \text{Reverse Direction (if Mirror\_rampdir} = 0)$$

For **"chop" mode** observations, the rates are by definition zero:

R_IT = R_FPS = 0.

The mirror deflection angle on the sky **(in arcsec)** as a function of boresight pointing history time (t_i) for the IT and FPS model respectively is computed as follows:

IT model:

$$\theta_{IT}(t_i) = 3600 * \text{beta\_actual\_IT} * (\text{scanMirrorAxisAngleDegrees} + R_{IT}\delta(t_i))$$

FPS model:

$$\theta_{FPS}(t_i) = \text{StartposSKY\_FPS} + R_{FPS}\delta(t_i)$$

where $\delta(t_i)$ represents the time difference between the "mirror SCLK_OBS" start time (=SCLK_OBS of DCE – MirrTimeOffset) and the pointing sample SCLK time (SCLKBGN_BPHF + t_i) in milli-seconds:

$$\delta(t_i) = 1000 * SCLKBGN\_BPHF + t_i - 1000 * (SCLK\_OBS - MirrTimeOffset)$$

where *MirrTimeOffset* is defined in the mirrorparameters.tbl file, the t_i and SCLKBGN_BPHF are from the input BPHF and SCLK_OBS is from the input DCE FITS header.

4.2.7. Uncertainties in Mirror Sky Positions

The uncertainties in mirror deflection angle on sky **(in arcsec)** as a function of boresight pointing history time are also computed for the IT and FPS models:

IT model:

$$\sigma[\theta_{IT}(t_i)] = \theta_{IT}(t_i)\sqrt{\frac{\text{var}(conv)}{conv^2} + \frac{\sigma^2(\text{beta\_actual\_IT})}{\text{beta\_actual\_IT}^2}}$$

where $\sigma(\text{beta\_actual\_IT}) = \frac{\text{sigma\_beta\_IT}}{\text{beta\_IT}^2}$ and sigma_beta_IT, beta_IT are defined in the mirrorparameters.tbl file.

conv ≡ DAC_to_DEG_conv as defined in section 4.2.4 and var(*conv*) is computed at scanMirrorDAC = ZP_Coarse:

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$$\mathrm{var}(conv) = [\ \mathrm{sig\_Coeff1}^2 + ZP\_Coarse^2\mathrm{sig\_Coeff2}^2 + ZP\_Coarse^4\mathrm{sig\_Coeff3}^2 +$$
$$2ZP\_Coarse\,\mathrm{cov\_Coeff12}|\mathrm{cov\_Coeff12}| +$$
$$2ZP\_Coarse^2\ \mathrm{cov\_Coeff13}|\mathrm{cov\_Coeff13}| +$$
$$2ZP\_Coarse^3\ \mathrm{cov\_Coeff23}|\mathrm{cov\_Coeff23}|\ ]*\left(\frac{1}{3600^2}\right)$$

FPS model:

$$\sigma[\theta_{FPS}(t_i)] = \theta_{FPS}(t_i)\frac{\sigma(\mathrm{beta\_FPS})}{\mathrm{beta\_FPS}}$$

where σ(beta_FPS) and beta_FPS are defined as sigma_beta_fps and beta_fps respectively in the mirrorparameters.tbl configuration file.

4.2.8. Output: The Mirror-Pointing History File

The main output from the software is a mirror-pointing history file in IPAC table format which contains all entries from the original (input) boresight-pointing history file (see section 4.2.3). Appended are five additional columns (theta, theta_sky, sigma_theta_sky, theta_sky_<mod> and sigma_theta_sky_<mod>). The columns with "_<mod>" represent quantities computed with the alternative model (the model which was not specified in the input mirror parameters table for the aperture name in question). These are given for comparison. Ancillary information on each column definition is contained in the header. Below is an example.

```
\character Mirror_Ptg_History_program = Output from MIRRORSYNCH, version  4.50
\character Mirror_Ptg_History_creation = Fri Dec  5 11:26:18 2003
\character comment = theta means scan mirror rotation about axis relative to optical-zero
\character comment = theta_sky means scan mirror deflection angle on sky relative to optical-zero using "Focal
Plane Survey" model
\character comment = sigma_theta_sky is the associated uncertainty
\character comment = theta_sky_IT means scan mirror deflection angle on sky relative to optical-zero using
"Instrument-Team" model
\character comment = sigma_theta_sky_IT is the associated uncertainty
\character comment = Output from getPH_offline, version 1.00
\character Date-Time = Wed Nov 12 12:30:34 2003
\character BPHF = /ssctst1/archive/raw/timeperiod/2003.10/pointingHistory/BPHF.0750556800.06.pntg
\int SCLKBGN = 751507200
\int SCLKEND = 751550400
\character comment = alpha means R.A in boresight
\character comment = delta means Dec in boresight
\character comment = gamma means twist angle in boresight
```

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```
\character comment = ualpha means standard deviation in alpha
\character comment = udelta means standard deviation in delta
\character comment = ualphadelta means costandard deviation in alpha and delta
\character comment = ugamma means standard deviation in gamma
\character comment = delta_y means change in the +Y direction
\character comment = delta_z means change in the +Z direction
|time    |alpha      |delta      |gamma      |ualpha     |udelta     |ualphadelta|ugamma     |delta_y
|delta_z    |theta      |theta_sky  |sigma_theta_sky |theta_sky_IT        |sigma_theta_sky_IT  |
|int     |double     |double     |double     |double     |double     |double     |double     |double
|double     |double     |double     |double          |double              |double              |
|msec    |degree     |degree     |degree     |arcsec     |arcsec     |arcsec     |arcsec     |arcsec
|arcsec     |degrees    |arcsec     |arcsec          |arcsec              |arcsec              |
 22361090  114.163658  -14.049350  192.913803    1.064257    1.064583   -0.013521    7.432666    0.005430
9.565355    0.103113   12.419406    0.046005        11.374552            0.604746
 22361590  114.163044  -14.051944  192.913940    1.064257    1.064583   -0.013521    7.432666    0.001897
9.568930    0.016209    2.832906    0.010494         1.788052            0.137944
 22362090  114.162431  -14.054539  192.914078    1.064257    1.064583   -0.013521    7.432666   -0.001621
9.572426   -0.070695   -6.753594   -0.025017        -7.798448           -0.328857
 22362590  114.161814  -14.057136  192.914246    1.064257    1.064583   -0.013521    7.432666   -0.012435
9.561730   -0.157599  -16.340094   -0.060529       -17.384948           -0.795659
 22363090  114.161203  -14.059731  192.914413    1.064257    1.064583   -0.013521    7.432666    0.001895
9.568943   -0.244504  -25.926594   -0.096040       -26.971448           -1.262460
 22363590  114.160589  -14.062325  192.914551    1.064257    1.064583   -0.013521    7.432666   -0.005232
9.568895   -0.331408  -35.513094   -0.131551       -36.557948           -1.729262
 22364090  114.159978  -14.064919  192.914688    1.064257    1.064583   -0.013521    7.432666   -0.008760
9.572444   -0.418312  -45.099594   -0.167063       -46.144448           -2.196064
 22364590  114.159364  -14.067517  192.914841    1.064257    1.064583   -0.013521    7.432666    0.001892
9.568955   -0.505217  -54.686094   -0.202574       -55.730948           -2.662865
 22365090  114.158750  -14.070111  192.915009    1.064257    1.064583   -0.013521    7.432666   -0.008686
9.579575   -0.592121  -64.272595   -0.238086       -65.317448           -3.129667
```

4.2.9. Termination

Summary output is appended to the log file (the log file is created if previously non-existent), which includes diagnostic reports for the Q/A Subsystem and the appropriate exit code issued to be picked up by the pipeline executive. A detailed list of log file contents is given in Section 6.1.2.

5. Algorithm Requirements

A. MIRRORSYNCH requires that the following keywords be present in the FITS-headers of the input DCE image: the instrument keyword, INSTRUME, the observation mode keyword CSM_MOD (or its equivalent as defined by the parameter "SM_MODE_KEYWD" in the include file mirrorsynch.h), the DCE order number keyword DCENUM and the SCLK_OBS (DCE start time) keyword. If any of these are not present, the program will abort with a message sent to standard output.

B. A tutorial which lists all the command-line options can be generated by typing "mirrorsynch" on the command line with no arguments. This tutorial will indicate which parameters are required and those which are optional. Optional parameters are assigned the default values defined in Table 1. If any of the required parameters are not specified, or are unacceptably out of range, the program will abort with a message sent to standard output to indicate this. Below is the tutorial generated when "mirrorsynch" is executed without any command line arguments.

```
Program MIRRORSYNCH, Version 4.6

Usage: mirrorsynch
  -n  <inp_namelist_fname>            (Optional)
  -i1 <inp_FITS_file>                 (Required)
  -i2 <inp_boresight_ptg_history_file> (Optional)
  -i3 <inp_mirror_parameters_File>    (Required)
  -o  <out_mirror_ptg_history_file>   (Optional; Default=FITS header updated)
  -c0 <Mirror_start_axis_DAC>         (Optional; if not specified, parameters
                                       c4,m1,m2,m3,m4,m5 must be
                                       specified; units=DAC)
  -c1 <Mirror_start_axis_angle>       (Optional; if not specified, parameters
                                       c4,m1,m2,m3,m4,m5 must be
                                       specified; units=degrees)
  -c4 <Stimcycle>                     (Optional, 1<=value<=63)
  -c5 <aperture_name_of_interest>     (Required)
  -m1 <mirror_scanpos1>               (Optional, units=DAC)
  -m2 <mirror_scanpos2>               (Optional, units=DAC)
  -m3 <mirror_relpos1>                (Optional, units=DAC)
  -m4 <mirror_relpos2>                (Optional, units=DAC)
  -m5 <mirror_stepoffset>             (Optional, units=DAC)
  -m6 <mirror_sky_scan_rate>          (Required, units=milli-arcsec/sec)
  -m9 <mirror_rampdir>                (Required, = 0(REV) or 1(FWD))
  -l  <log_fname>                     (Optional, Default=`stdout')
  -a  <ancillary_file_path>           (Optional, Default = ./)
  -v  (verbose output)
  -vv (superverbose output)
```

6. Output

6.1. MIRRORSYNCH Output Summary

MIRRORSYNCH is capable of generating the following output:

A.) Standard-output processing and status messages.

B.) A Mirror-Pointing History File (MPHF) containing boresight-pointing information AND mirror (axis and sky) deflection angles as a function of pointing time.

C.) A log file containing processing statistics, status messages and ancillary information.

All MIRRORSYNCH disk output is written to the pathnames that are specified with the output filenames in the command-line or namelist inputs.

6.2. MIRRORSYNCH Log-File Output

The information stored in the log file at the output of this program includes: program name and version number, values of all namelist and/or command-line inputs, a message indicating the type of calculation performed, status code, processing time, date and time, and a message indicating program termination. An example of the log file output is shown below. More diagnostic information can be displayed by executing the program with the –v and –vv on the command line.

```
Output from mirrorsynch_compute_results:

Mirror coarse DAC position at start of DCE = 2007 DAC
Mirror fine DAC position about axis at start of DCE = 1700 DAC
Fiducial offset to add to internal CSM_PRED from mips24 relative spot measurements = -
0.000000 DAC
Nominal Mirror position about axis at start of DCE (CSM_PRED; no "offset" added) =
1963.500000 DAC
Mirror position about axis at start of DCE (CSM_PRED; with "offset" added) =
1963.500000 DAC
Mirror position about axis at start of DCE from Zero Point = 43.500000 DAC
Mirror angle about axis at start of DCE = 0.210106 degrees
Mirror position on sky at start of DCE relative to DCENUM=0 (CSM_SKY) using IT method
= 21.245794 arcsec
Mirror position on sky at start of DCE relative to optical-zero position using IT
method = 23.176992 arcsec
Mirror position on sky at start of DCE relative to optical-zero position using FPS
method = 24.235680 arcsec
Mirror-axis-angle to sky-angle (dimensionless) scale factor (IT-model) for this DCE
mode = 0.030642
DAC to sky-angle scale factor (FPS-model) for this DCE mode = 0.000002701100929
(radian/DAC)
Mirror scan rate on sky = 19173.0000000000000 milli-arcsec/sec
Mirror rot'n rate about axis = -0.0001738085703 degrees/milli-sec
Coefficients of DAC-to-arcsec quadratic conversion model = 26.190000000; -0.008828000;
0.000002213
Sigma of Coeffs of DAC-to-arcsec quadratic conversion model =  0.600000000;
0.000060000;  0.000000060
Covariances of Coeffs of DAC-to-arcsec quadratic conversion model =  0.000000000;
0.000000000;  0.000000000
```

```
Method used: 2 (1 => Intrument Team method; 2 => Focal Plane Survey method)
MirrTimeOffset = 0.765000 real seconds

Program MIRRORSYNCH, Version 4.6
Input FITS File = ./testing/test_scan.fits
Input Mirror Parameters File = ./testing/mirrorparameters.tbl
Input Boresight Pointing History File = ./testing/ptghistory.dat
Output Mirror Pointing History File = ./testing/mirrorhistory.dat
Mirror_Sky_Scan_Rate = 19173.000000
Mirror_rampdir = 0
Desired aperture (FOV) name = MIPS_24um_center
Mirror_scanpos1 = 2007
Mirror_scanpos2 = 2007
Mirror_relpos1 = 2048
Mirror_relpos2 = 2048
Stimcycle = 33
Mirror_stepoffset = -29
Mirror_Pos_Zero_Point_coarse = 2007
Mirror_Pos_Zero_Point_fine = 2048
Verbose flag = 0
Super-verbose flag = 0
Debug flag = 0
Performed Mirror-Pointing History computation for input FITS image.
Program mirrorsynch: Status Message: 0x0000
Normal exit from Function 0x0000: LOG_WRITER
Processing time: 0.110000 seconds
Current date/time: Thu Apr 21 14:53:23 2005
Program MIRRORSYNCH, version 4.6, terminated.
```

7. Testing

MIRRORSYNCH has been successfully unit-tested as a stand-alone program for a variety of different input cases. The tests were designed to check MIRRORSYNCH robustness and capability of generating corrected results.

Here is a summary of the unit tests that were conducted:

1. Tested MIRRORSYNCH on simulated MIPS DCE images with different values for the relevant FITS keywords and a simulated boresight-pointing history file.

2. Executed MIRRORSYNCH with inputs read from and output written to directories different from where the program was run. Both namelist and command-line input mechanisms were exercised.

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3. Executed MIRRORSYNCH for all combinations of input parameters, in order to test that they function properly.

8. Usage Examples

Using a namelist file with verbose (-v) output re-directed to a file “out.log”:

```
MIRRORSYNCH –n mirrorsynch.nl -v | & tee out.log
```

Without using a namelist file:

1. If the two mirror start position parameters: “Mirror_start_axis_DAC” and “Mirror_start_axis_angle” **are available** (pre-computed) on input:

```
mirrorsynch -i1 test_scan.fits -i2 ptghistory.dat -i3
mirrorparameters.tbl -o mirrorhistory.dat -c0 1963.5 -c1 0.210106
-m6 19173 -m9 0 -a ./ -c5 MIPS_24um_center
```

2. If the two mirror-position parameters: “Mirror_start_axis_DAC” and “Mirror_start_axis_angle” **are NOT available,** then the following six mirror parameters must be specified: Stimcycle; Mirror_scanpos1; Mirror_scanpos2; Mirror_relpos1; Mirror_relpos2; Mirror_stepoffset:

```
mirrorsynch -i1 test_scan.fits -i2 ptghistory.dat -i3
mirrorparameters.tbl -o mirrorhistory.dat -c4 33 -m1 2007 -m2
2007 -m3 2048 -m4 2048 -m5 -29 -m6 19173 -m9 0 -a ./ -c5
MIPS_24um_center
```

9. Glossary

AOR	Astronomical Observer Request
BPHF	Boresight-Pointing History File

THIS IS A PRELIMINARY DOCUMENT, the module described here may or may not be utilized in the final pipelines as described.

DAC	Digital-to-Analog Conversion
DCE	Data Collection Event
FPS	Focal Plane Survey
DN	Data Number
IOC	In-Orbit Checkout
LSB	Least Significant Bit
MIPL	Multi-Mission Processing Laboratory
MIPS	Multi-band Imaging Photometer for SIRTF
MPHF	Mirror-Pointing History File
SDS	Subsystem Design Specification
SIRTF	Space Infrared Telescope Facility
SIS	Software Interface Specification
SSC	SIRTF Science Center
TBD	To Be Determined
TBR	To Be Resolved