NISTAR Processing

This report is written to describe the various levels of NISTAR processing and provide an overview of the processing algorithms.

Level 0 Processing

Level 0 Processing takes the raw data and sorts it, filters it, and organizes it into one file per day.

The NISTAR ground processing software accepts inputs as sequential print text files for Level 0 processing. These files are assumed by the code to have the following characteristics:

- One or more header lines which contain mnemonics for each data field.
- Filename convention:
  - hk_apid##_VC$_s<START TIME>_e<END TIME>.txt for AppID 37, 82, 86 files, where ## = [37, 82, 86], $ = [0, 1], and <START TIME> and <END TIME> are formatted YYYY_DOY_HHMMSS
  - DSOC_<START TIME>_<END TIME>.txt for DSCOVR Ephemeris files, where <START TIME> and <END TIME> are formatted YYYYDOYHHMMSS
  - DSCOVR_SLP_?????Ephem_<START DATE>.txt for Lunar and Solar Ephemeris files, where ????? = [Lunar, Solar] and <START DATE> is formatted YYYYDOY.
  - ****_att_data_VC$_<START TIME>.csv for Quaternion files, where **** is the source of file (e.g. swpc, moc, ngdc, etc.), $ = [0, 1], and <START TIME> is formatted YYYY_DOY_HHMMSS
  - nistar_misc_****_VC$_<START TIME>_<END TIME>.txt for Miscellaneous science data files, where *** is the source of file (e.g. swpc, moc, ngdc, etc.), $ = [0,1], and <START TIME> and <END TIME> are formatted YYYY_DOY_HHMMSS
- Contains less than 120,000 records in a single AppID file. This corresponds to about 1.4 days of AppID 82 or Misc data, 14 days of AppID 86 data, or 41.7 days of App ID 37 data. In practice the files do not contain data for more than 24 hours.
- Contains less than 100,000 records in a single ephemeris file. These files usually cover 30 days of data (43,200 records).
- Contains less than 86,400 records in a single quaternion file. The largest file so far has contained less than 3,000 records.
- Data is comma separated and corresponds to the mnemonics in the header line. Time tag formats are consistent for each particular type of data file.

Level 0 processing will accept these files as input and output new text files, one file per Julian day per data type. Note Julian days begin at 12:00 UTC each day and are measured in days since 12:00 UTC January 1st 4713 BCE. These level 0 outputs will have the following characteristics:

- Filename convention <DATA TYPE>_<JULIAN DAY>.txt, where <DATA TYPE> is one of [AppID82, AppID86, AppID37, AppIDMisc, Quaternion, DSCOVREphemeris, LunarEphemeris, SolarEphemeris] and <JULIAN DAY> is a decimal integer.
- Sorted chronologically.
- Subsecond field has been converted from subsecond counts (modulo 65536) to a double precision floating point representation, when necessary.
- Filtered to remove data points which have values outside of the assumed limits. See the Data Format Control Book for a list of limits.
- Times which are before the launch date or after the time of processing (i.e. in the future) are also filtered out.

Level 1A Processing

Level 1A Processing takes the sorted filtered Level 0 output files and incorporates geolocation algorithms to determine what objects were in the field of view while converting digital numbers to engineering units in preparation for Level 1B Processing.

The inputs to Level 1A Processing are the output text files from Level 0 Processing which have been sorted and filtered to only include data with values within the assumed ranges. In addition the calibration parameters are accepted as inputs. When in real-time processing mode, L1A processing will lag behind the present by a user determined number of lag days to allow for data acquisition delays.

Level 1A Processing includes the following algorithms:

- Conversion from digital number units to actual engineering units (Watts, degrees Celsius, etc.)
- Ephemeris and quaternion data are used to determine the object(s) in the NISTAR field of view.
  - Convert quaternions to Euler attitude matrices, incorporating the NISTAR-EPIC pointing offset from the calibration tables.
  - Interpolating ephemeris and quaternion data to the same time values.
  - Compute right ascension and declination of orbit from ephemeris data.
  - Compute subsatellite latitude and longitude from right ascension and declination, as well as from the computed Greenwich hour angle.
  - Compute DSCOVR ephemeris with respect to moon.
  - Compute lunar subsatellite latitude and longitude following Escobal "Methods of Orbit Determination", Appendix I, Transformation 26.
  - Get Earth and Lunar Sun Angles (the angles between the DSCOVR-earth and moon-earth vectors, respectively, and the earth-sun vector).
  - Determine apparent size of Earth and moon from ephemeris data (i.e. how large do they appear to the instrument)
  - Using all this information to determine the object(s) in the field of view. Field of view incorporates aperture sizes and separation from calibration parameters. The choices for
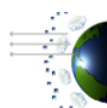
NISTAR View are: 1. Earth only, 2: Moon only, 3: Deep Space, 4: Earth and Moon, 0: Partial Earth only (part of Earth outside FOV)

- Convert photodiode data to units of current and sort data by NISTAR View.
- Convert radiometer data to units of power, and determine decimated radiometer data, which is manually forced to a 1/6 Hz cadence when possible. This is the nominal cadence for VC1 data, while VC0 data is available at 1 Hz. The cadence switches when VC0 data is not available can cause difficulties during L1B processing.
- Output ephemeris data (including solar angles, and subsatellite latitude/longitude coordinates), converted radiometer data, and converted and sorted photodiode data to text file for Level 1B processing.
- Output all data to HDF file.

Output files from Level 1A Processing have the filename convention <DATA TYPE><JULIAN DAY>.txt. Note there is no underscore. <DATA TYPE> is one of [GeoLocation, LunarLocation, SolarLocation, RadiometerIrradiance, RadiometerIrradianceDecimated, PhotodiodeEarth, PhotodiodeMoon, PhotodiodeDeepSpace, PhotodiodeEarthAndMoon]. In addition HDF files are output with filename convention nist_1a_YYYYMMDD_<MID DAY LAT LONG>_<REVISION NUMBER>.hdf, where <MID DAY LAT LONG> has formatting such as 14s173w zero-padded, and <REVISION NUMBER> is a 2 digit integer also zero-padded. Subsequently in a separate routine HDF files are converted to hdf5 files with the same naming convention and .h5 file extension.

Level 1B Processing

Level 1B Processing is the level where true irradiances are computed, through demodulation when applicable. Ephemeris and engineering data are used to sort radiometer data by band and view object. Level 1B products include demodulated radiometer data and time averages of both radiometer and photodiode data.

The inputs to Level 1B processing are the processed ephemerides, radiometer data, and photodiode data text files produced by Level 1A processing. To L1B process a particular Julian day, it is required to have data from the previous and subsequent Julian day available. Therefore when in real time processing mode L1B processing will lag behind L1A by one day.

Level 1B Processing includes the following algorithms:

- For each day of processing, read L1A data including last two hours of previous Julian day, entire current Julian day, and first two hours of the next Julian day.
- Determine the number of samples per cycle of the radiometer data via an FFT of the input radiometer power data. This algorithm will use a maximum of 65536 data points starting from the first data point where all three receiver cavity shutters were open. Then the samples per cycle are computed by examining the maximum bin of the FFT.

- If the computed number of samples per cycle is outside of a set of limits it is assumed that the shutter was not moving for the entire Julian day. This would be the case primarily for two scenarios: either autocycle is turned off, or the shutters were closed all day due to a spacecraft safehold condition. These limits determine whether the code will call the appropriate algorithms for demodulation or instead for running mean computation.
- The computed samples per cycle are forced to one of a set of values corresponding to the various operating modes of the instrument over its lifetime. These are 1 minute, 10 minute, 20 minute, 30 minute, and 40 minute shutter cycle periods, as well as the decimated (1/6 Hz) corresponding periods. At various times during the mission the instrument has been operated with 10, 20, 30, and 40 minute shutter autocycle periods. Days where the shutter did not move are forcibly given a shutter period of 1 minute. Due to the NISTAR Timing Anomaly (see NISTAR Quality Report) a 10 minute nominal period is actually closer to 638 seconds and similar discrepancies are seen for the other period lengths.
- Here the flow of processing splits according to whether demodulation or running mean filtering is to be done.
- For demodulation (autocycle on):
  - In these algorithms "Nominal Demodulation" refers to using the entire data set to extract the amplitude of the noisy square power signal. "Manual Demodulation" refers to using only the latter half of the data at each shutter position for demodulation. The purpose is to restrict the demodulation to use data which has been thermally stabilized. The NISTAR Quality Report discusses the thermal stability issue in more detail.
  - Prepare the radiometry data for Manual Demodulation:
    - Determine times of shutter motion.
    - For each half period (during which the shutter is not moving), save only the latter half of data points.
    - Has the effect of eliminating points which were far from thermal equilibrium, as well as making the period of the signal uniform (see NISTAR Timing Anomaly in NISTAR Quality Report).
  - Manual Demodulation:
    - Normalize the shutter values to range from 0 to 1, instead of 2 to 198.
    - Determine samples per cycle. This is not the same value as previously computed due to the eliminated points during previous algorithm.
    - Execute demodulation routine using the four boxcar phase sensitive demodulation algorithm. First two and last two shutter periods are zero-padded. See Eq. 1 below:
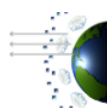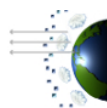
$$r_J = real\left[\frac{\displaystyle\sum_{M=J-N+1}^{J}\sum_{L=M}^{M+N-1}\sum_{K=L-N+1}^{L}\sum_{I=K}^{K+N-1}e^{i2\pi I/N}\phi_I}{\displaystyle\sum_{M=J-N+1}^{J}\sum_{L=M}^{M+N-1}\sum_{K=L-N+1}^{L}\sum_{I=K}^{K+N-1}e^{i2\pi I/N}\psi_I}\right]$$

Eq. 1

- o Demodulation: Same routine, but using all radiometer power data. This is a less accurate irradiance measurement due to the thermal equilibrium issues.
- For running mean (autocycle off or safehold):
  - o Replace the shutter values with a reference signal with a period of one minute between open and closed.
  - o Compute a one minute running mean of the signal to filter noise in lieu of demodulation, zero-padding first two and last two minutes.
- Here the flow of processing is united again for either autocycle scenario.
- Sort radiometer and photodiode data by band (A = Total channel, B = Solar Reflected, C = Near IR Solar Reflected) and by NISTAR View (object in FOV).
- Apply appropriate dark space offsets to remove background via linear interpolation from on-orbit dark space calibration data.
- Apply other calibration parameters, such as absolute scale from ground tests and aperture sizes to provide irradiance.
- Compute time averages of demodulated (or running means) radiometer data:
  - o There are five L1B average products, corresponding to the view object and the average bin length: Earth Four Period, Earth Four Hour, Earth Daily, Deep Space Four Period, and Deep Space Four Hour.
  - o These are computed on sliding bins with one hour steps, e.g. for Earth Four Hour averages the first bin is 00:00 to 04:00, the second bin is 01:00 to 05:00, etc.
  - o Ignores radiometer or photodiode data with values of zero.
  - o After completion of absolute calibration (next release), uncertainty values will no longer be placeholder values of zero.
- All the above algorithms are done twice for each Julian Day, once for nominal cadence data (whatever the available data is without filtering, can switch between VC0 and VC1 cadences) and once for decimated data (forced to VC1 cadence). The decimated products are labeled as "Decimated" to distinguish them.
- Output data to HDF and text files.

Output files from Level 1B Processing have the filename convention <DATA TYPE><JULIAN DAY>.txt. Note there is no underscore. <DATA TYPE> is one of [DemodulatedRadiometerIrradiance, ManualDemodulatedRadiometerIrradiance, EarthSignalIrradiance, Level1BAveragesFourPeriodEarth, Level1BAveragesFourHourEarth, Level1BAveragesDailyEarth, Level1BAveragesFourPeriodDeepSpace, Level1BAveragesFourHourDeepSpace] along with their "Decimated" equivalents. In addition HDF files are output with filename convention nist_1b_YYYYMMDD_<MID DAY LAT LONG>_<REVISION NUMBER>.hdf, where <MID DAY LAT LONG> has formatting such as 14s173w zero-padded, and

<REVISION NUMBER> is a 2 digit integer also zero-padded. Subsequently in a separate routine HDF files are converted to hdf5 files with the same naming convention and .h5 file extension.