Automatic Lightcurve Fitting for MANOS

January 14, 2014

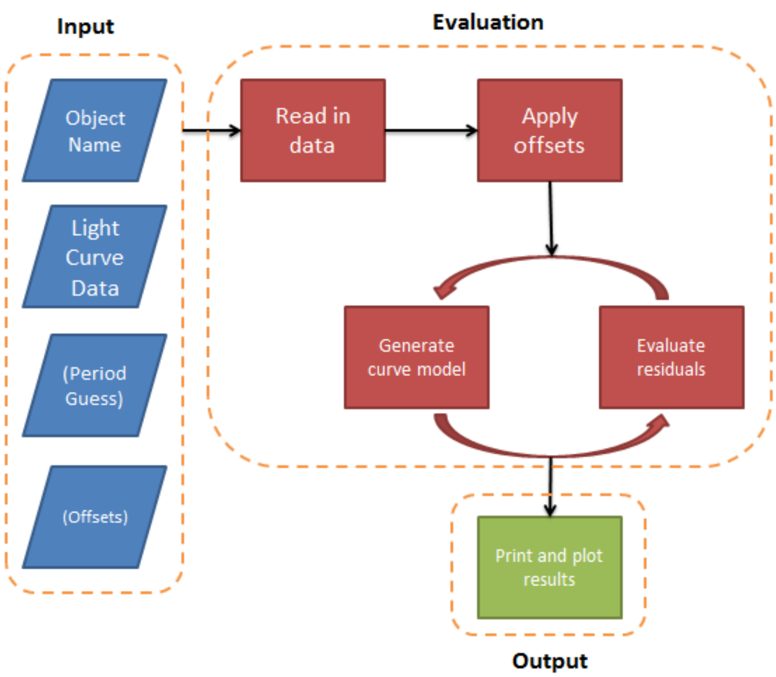
1 Introduction

This document is intended to be an introduction to the manosCurveFit.py program used for automatic lightcurve fitting, part of the automation software for the Mission-Accessible Near-Earth Object Survey (MANOS). The program is designed so that minimal user input is necessary to run, but additional inputs are available for customization of the processing procedures and output forms. The backbone of the fitting method is a nonlinear least squares minimization using the Fourier fitting method outlined in Harris et al. 1989.

1.1 System Dependencies

This software was developed and tested on Python 2.7.1, and imports from the following typically pre-installed packages: *operator, os, time,* and *sys*, and the following typically non-pre-installed packages: *lmfit, matplotlb, numpy.* The latter set of packages are commonly used for scientific applications and stable builds should be easily found.

1.2 System Overview



The fitting routine may be generally divided into input, evaluation, and output portions, each requiring one method call by the user. The inputs in parentheses are not required for the fitting to work, but a guess at the rotational period may significantly contrain the search space, and if data is taken over multiple nights and/or by different instruments, offsets will be required to normalize the magnitudes to some baseline. A number of other inputs may also be supplied to constrain or expand the search space. The light curve data is then read in from a text file with user-defined columns. Two kinds of magnitude offsets are then applied: offsets by night/instrument, if provided, and then a normalizing offset which subtracts the weighted average magnitude of the set from the entire set. The latter offset is necessary in order to center the data points on the y-axis for fitting purposes, and may be used in this context because only differential magnitudes are needed. For each period to be checked, a least squares minimization is performed for each order of Fourier coefficients from two to six, un$k$less specified otherwise in the inputs. The parameters that generate the best fit to the data are kept and printed at the end, along with the lightcurve and residual plots.

1.3 Fitting Rationale

This fitting routine is based on equations 1, 2, and 3 from Harris et al. 1989, where the model is based on the Fourier Series

$$H(\alpha,t) = \bar{H}(\alpha) + \sum_{L=1}^{m} A_L sin\frac{2\pi L}{P}(t-t_0) + B_L cos\frac{2\pi L}{P}(t-t_0), \tag{1}$$

where $\bar{H} = 0$ because absolute magnitudes are not necessary for MANOS, and m (the series order), P (the period), and A_L and B_L (the Fourier coefficients) are free parameters. The residual of a particular observation i may be obtained by

$$\frac{\delta_i}{\epsilon_i} = \frac{V_i(\alpha_j) - H(\alpha_j, t_i)}{\epsilon_i}, \tag{2}$$

whereα_j is the reference phase angle on the j^{th} night, t_i is the time of the i^{th} observation, and ϵ_i is the error of the measurement. In the context of NEOs, the phase angle may very well change, particularly as targets pass very close to Earth. However, the majority of MANOS targets will be observed for a short enough period of time that α will be assumed to be a constant. As such, manosCurveFit does not take phase angles into account. The least squares minimization is then performed on the bias-corrected variance, given by

$$s^2 = \frac{1}{n-k}\sum_{i=1}^{n}\left(\frac{\delta_i}{\epsilon_i}\right)^2 = minimum, \tag{3}$$

where n is the total number of observations, $k = 2m + 1$, where m is defined in 1. The total number of nights of data is also added into k in the form that Harris et al. uses, but here, this again needs not be considered because we are concerned with differential photometry, and offsets for different nights will be provided as necessary.

By default, the program will run the fit from $m = 2$ to $m = 6$. The minimum of order two is due to the fact that asteroid light curves are expected to be double-peaked (except for some cases of unstable rotation or degenerate cases of near-spherical bodies), and the maximum of order six is used to prevent over-fitting (**TODO- better explanation?**).

2 Input, Evaluation, and Output Methods

The software handles data input by reading text files and storing user-defined data columns as numpy arrays in a *lightCurveData* object. Evaluation is handled by the *fitData* function, which utilizes *lmfit*'s minimization routine with free parameters given as Parameter object inputs. Output is handled by the *outputResults* function, which has options to display results in various ways.

2.1 The `lightCurveData` Class

class `lightCurveData`(objectName, fileNamesAndFormat[, offsetsList = None])

Creates a lightCurveData object which is used to read in and manipulate the dataset.

Parameters

- **objectName** (string) - name of the object associated with the dataset

- Example: 'Spartacus20090130'
- Stored in lightCurveData.name

- **fileNamesAndFormat** (list of dictionaries) - names of text files to be read in, along with the associated column definitions in the data (format specification)
  - Example:

    ```
    fileName = 'Spartacus20090130_MANOS.txt'
    # list of lists specifying ['property',column] in the text file
    formatSpec = [['night',0],['jd',3],['diffMag',6],['magErr',7]]
    fileNamesAndFormat = [{fileName:formatSpec}]
    ```

  - Multiple key/value pairs may be used when multiple text files are to be used
  - `'jd'` (Julian date), `'diffMag'` (differential magnitude), and `'magErr'` (magnitude error) must be specified to run the program, additional properties may also be stored in the `lightCurveData` object
  - Remember that Python indexes from zero, so the left-most column in the text file is column 0
  - Any white space in the text file is considered a delimiter (leading and trailing white space is ignored)
  - Stored in lightCurveData.data

- **offsetsList** (list of dictionaries, `None` = no offsets) - offsets associated with nights in each text file
  - Example: [{1:0.0,2:-0.04,3:0.464}]
  - Key/value pairs must be int/float pairs, where the key is the night number, and the value is the offset
  - Multiple dictionaries may be used when multiple text files are to be used- when this is done, the order of these dictionaries must correspond to the order of the files names and specifications used in `fileNamesAndFormat`
  - Keys may be repeated as long as they are in different dictionaries
  - `'night'` property must be specified in the format to use offsetsList

2.2 The `fitData()` Function

`fitData`(lightCurveData[, method = None[, periodGuess = None[, minPeriod = None[, maxPeriod = None[, orderRange = [2,6]], timer = False]]]]])

- **lightCurveData** (lightCurveData object)

- **method** (string) - method to be used for traversing the search space of periods: `None`, `'single'` or `'range'`
  - when method is `None`, a maximum recoverable period is calculated using the Nyquist Criterion for non-uniform samples[2] and periods are checked at 15 minute (0.25 hour) intervals; periodGuess is ignored in this case
  - when method is `single`, periodGuess must be provided as an int or a float, which serves as the only inital period used in the minimization
  - when method is `range`, periodGuess must be provided as a three-element list of `[start, stop, step]` integers or floats, which is then automatically converted into a list of initial periods for minimization

- **periodGuess** (int or float or three-element list of ints or floats) - the initial period used for minimization, given in hours; this provides a starting point for the the period parameter, which does not remain fixed during the minimization

- **minPeriod** (int or float) - the hard lower limit for the period fitting, no period below this value will be attempted in the evaulation
- **maxPeriod** (int or float) - the hard upper limit for the period fitting, no period above this value will be attempted in the evaluation
- **orderRange** (two-element list of ints) - range of m values to be attempted in the Fourier model, as outlined in the Fitting Rationale section
- **timer** (boolean) - when `True`, the script will display the runtime of this function at the end of the run

Returns (bestFit, bestOrder, periodsTested, periodErrors), where bestFit is a Minimizer object, bestOrder is an int, and periodsTested and periodErrors are corresponding lists of floats.

2.3 The `outputResults()` Function

`outputResults`(fit, m, lightCurveData[, printReport = True[, plotFullPeriod = True[, plotErrorbars = True[, phaseFoldData = True[, plotResiduals = False[, periodErrors = None]]]]]])

- **fit** (Minimizer object) - the bestFit object returned by `fitData()`
- **m** (int) - the bestOrder returned by `fitData()`
- **lightCurveData** (lightCurveData object) - the lightCurveData object used for this run
- **printReport** (boolean) - when `True`, the resulting variables and correlations will be printed at the end of the run
- **plotFullPeriod** (boolean) - when `True`, the full period generated by the fit will be plotted, when `False`, the model will be plotted as far as the data points go
- **plotErrorbars** (boolean) - when `True`, the error bars on the dataset will be plotted
- **phaseFoldData** (boolean) - when `True`, a single period will be plotted, with the dataset phase folded and the x-axis showing Julian days since the first data point, when `False`, the model will be plotted over the entire set of data, and the x-axis will show actual Julian dates
- **plotResiduals** (boolean) - when `True`, a subplot will be included showing the residuals for each data point
- **periodErrors** (n by 2 list of lists) - when provided, a second figure will be plotted showing the mean RMS of the residuals as a function of period

3 Future Improvements

- phase angle considerations
  - polling from the Lowell ephermeris database

References

[1] Harris, A. W., et al. "Photoelectric observations of asteroids 3, 24, 60, 261, and 863." Icarus 77.1 (1989): 171-186.

[2] Harris, A. W. & Lupishko, D. F. 1989, “Photometric Lightcurve Observations and Reduction Techniques” in “Asteroids II,” ed. R. P. Binzel, T. Gehrels, & M. S. Matthews.