A COMPUTER PROGRAM TO REDUCE PHOTOMETRIC DATA

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Abstract

A description is given of a computer program written in BASIC and designed to yield ΔV and ΔB magnitudes in the standard UBV system. The program also yields other relevant data, such as standard deviation, mean error, Julian Date, and air mass.

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1. Introduction

The authors began photometric observations at the Dance Hill Observatory in June, 1981. The observatory, located near Ayr, Ontario, is equipped with a 36.2 cm. f/5 reflector and a photometer manufactured by Pacific Precision Instruments.

Meter deflections were examined visually and their averages written on data report forms. The sequence of observations consisted of three sets of comparison-sky-variable-sky, followed by a check star sky reading, if any.

Also recorded were the local sidereal times and universal times of the readings, filter and diaphragm settings, voltage applied to the 1P21 tube, and sky conditions.

To analyze the meter deflections and their associated gain steps on the amplifier, a computer program was written on a Texas Instruments 99/4 home computer. Only slight modifications will be needed to run this BASIC language program on other home computers, thus giving it wide applicability. One of us (MK) has modified the program to reduce data in U, B, or V on an Apple home computer. The program provides all of the data necessary for the plotting of a light curve of a variable star or asteroid, and subsequent analysis by methods such as least squares. A flow chart of this program appears in Figure 1.

2. Determination of Extinction and Transformation Coefficients

Before a set of deflections can be reduced with the computer, the extinction coefficients k' and k'' and transformation coefficients ε_V and ε_B must be known. In this section we show how these values are found.

To determine k', which varies from night to night, observations must be made of some one star throughout the night (every hour is adequate). This so-called extinction star can be any one of the comparison stars in the observing program, as long as its stability has been well established.

A typical sequence of observations would be to measure the comparison star near the meridian, where the air mass X will be at a minimum ($X \simeq 1$), and every hour as long as possible after that. Since only three observations in quick succession of the comparison and sky background are needed each hour, it should not interfere seriously with a regular sequence of observations on other stars.

To determine k', input the data in the usual way (see section three), with a dummy value of k'. The output data will include three values of the air mass and corresponding values of the raw instrumental magnitudes of the extinction star. All three values should commingle around a central value, although at large air mass there may be large scatter.

After running through five sets of data spanning five hours, which is typical, plot the raw instrumental magnitudes *versus* air mass X. The values should fall along a straight line whose slope is k, the extinction coefficient.

This value is related to k' and k'' by the formula

$$k = k' + k'' \, (B-V). \quad (1)$$

In the V band, k'' is 0.00, so the slope of the line equals k'. In the B band, however, k'' is approximately -0.03, so k' must be calculated.

In addition to the extinction coefficients, the transformation coefficients must be determined for your system. They provide a measure of how your system relates to the standard UBV system.

The authors have written a separate program to calculate these coefficients. It is broadly similar to the data reduction program, but differs from it in the following respects.

A star pair is selected from the list of standards by Crawford *et al*. (1971) and six sets of measurements are taken.

The input data list is considerably shorter: gains of the two stars and the sky; local sidereal times for the six observations; right ascension and declination of both stars; k' and k''; and Δ(B-V) and ΔV.

The formula from Hall and Genet (1982) to compute the transformation coefficient in V is

$$\varepsilon_V = \frac{\Delta V - \Delta v + k' \, \Delta X + k'' \, \langle X \rangle \, \Delta(B-V)}{\Delta(B-V)}, \quad (2)$$

where Δv is the average raw instrumental differential magnitude based on the six intercomparisons, ΔX is the average differential air mass, $\langle X \rangle$ is the average air mass, and ΔV and $\Delta(B-V)$ are both known quantities for stars on the list of Crawford *et al*. The extinction coefficients k' and k'' have to be determined by the method mentioned earlier. A similar formula is used to compute ε_B. Values of ε_V and ε_B are typically between -0.2 and +0.2, but ideally they should be as close to zero as possible.

3. Description of Computer Program

The program begins by requesting input data. The list seems long, but can usually be typed in a minute or two.

The following values must be entered: amplifier gains for the observations of the variable star, comparison star, check star, and sky; local sidereal times corresponding to the three variable star measurements; right ascension and declination of the variable, comparison, and check stars; the extinction coefficients k' and k''; Δ(B-V) in the sense of variable and check minus comparison; day, hour, and minute of UT; distance from the sun to the earth in astronomical units; longitude of the sun for 0 hour UT on the day of the observation and the day following; and finally, a value for your transformation coefficients ε_V and ε_B.

Values for the earth-sun distance and sun's longitude can be found for each day in The Astronomical Almanac.

The program next defines your transformation coefficients in the B band, the conversion from degrees to radians, your latitude, the obliquity of the ecliptic, and the light travel time from earth to sun.

The computer then reads the set of values typed into the data statement. These are the actual meter deflections recorded at the telescope.

All gains are then reduced to the gain of the variable star, and the sky background is then subtracted from the measurements of each variable, comparison, and check star.

As each variable observation is set between two comparison observations, the comparison observations are reduced to yield three interpolated comparison measurements. Thus, three variable observations correspond to three interpolated comparison observations.

The measurements are then converted to magnitudes with the formula

$$m = -2.5 \log d, \quad (3)$$

where m is the raw instrumental magnitude and d is the deflection recorded on the meter for the star minus sky. The comparison values are then subtracted from the variable star values, to yield Δm.

Control then shifts to a subprogram to compute the standard deviation and mean error of the three observations. The formula used to compute standard deviation is

$$\sigma = \sqrt{\frac{\Sigma(\Delta m - \Delta\bar{m})^2}{2}} . \quad (4)$$

The mean error is found by dividing this standard deviation by the square root of 3, where 3 is the number of measurements taken during observation.

The hour angles are computed next by subtracting the star's right ascension from the sidereal time, multiplying by 15, and converting to radians. (This conversion to radians is necessary only if your computer work is in radians instead of degrees, as is most common.)

Control then shifts to a subprogram that calculates the air mass. This is done in two steps. First, the air mass, X, is approximated by sec z, which can be computed with the formula

$$\sec z = (\sin\phi \ \sin\delta + \cos\phi \ \cos h \cos\delta)^{-1}, \quad (5)$$

where ϕ is the observer's latitude, δ is the star's declination, and h is the star's hour angle. Second, to improve the approximation we use the formula

$$X = \sec z \ [1 - 0.0012 \ (\sec^2 z - 1)]. \quad (6)$$

This formula works quite well up to sec z = 4.

Once the air mass has been calculated for the three variable star measurements and the three interpolated comparison measurements, the differential and average air masses are computed. The computer next calculates the extraterrestrial instrumental differential magnitudes, using separate equations for the V and B bands. The input value of the V band transformation coefficient acts as a flag. If the values in the data statement are in the B band, the input value for V band coefficient is 0. If the values are in the V band, input the V coefficient determined in your system. The formula to compute these differential magnitudes is

$$\Delta v_o = \Delta v - k'_v \, \Delta X - K''_v \, \langle X \rangle \, \Delta(B-V), \qquad (7)$$

where Δv is the Δm value computed earlier, k'_v and k''_v are the extinction coefficients, ΔX is the differential air mass, $\langle X \rangle$ is the average air mass, and $\Delta(B-V)$ was included in the input data. The equation for the blue band is analogous.

The program next determines the standard differential magnitudes, which are the final delta magnitudes in the printout. The formula to compute these is

$$\Delta V = \Delta v_o + \varepsilon_v \, \Delta(B-V). \qquad (8)$$

Again, the equation for the blue band is analogous.

Next, the program computes the geocentric Julian date. For this computation two values of the solar longitude are needed, as the computer interpolates to obtain the correct value for the hour and minute of observation. Included in the program are statements that define the Julian date for 0 hours UT on the 0 date of each month. These statements have to be updated each year. The Julian dates can be found in The Astronomical Almanac. The Julian date is then calculated by adding the UT of observations to the values already present in the define statements. Altering one line in the program will assure that the UT value is added to the correct month.

Finally, the program computes the heliocentric correction, HC, with the equation

$$HC = kR\,[\cos\theta \cos\alpha \cos\delta + \sin\theta\,(\sin\varepsilon \sin\delta + \cos\varepsilon \cos\delta \sin\alpha)], \qquad (9)$$

where k is the light travel time for 1 astronomical unit (0.0057755 day), R is the actual distance between earth and sun in AU, θ is the geocentric longitude of the sun, ε is the obliquity of the ecliptic (23° 27'), α is the star's right ascension, and δ is the star's declination. This heliocentric correction is added to the geocentric Julian date to yield the heliocentric Julian date.

The values printed out by the computer are three delta magnitudes for variable minus comparison and one delta magnitude for check minus comparison; the standard deviation and mean error; Julian date (hel.); and three air mass values and three interpolated comparison magnitudes (the raw instrumental magnitudes). The air mass values and raw instrumental magnitudes are useful for the graphical determination of k' described in Section 2.

The program is constructed in such a way that it can rather easily be altered to handle observations in the U band as well, and it can also be adapted for pulse counting by substituting integration times for gain settings.

A numerical example, including the input and output data, is given in Table I.

To accumulate observations of a particular variable star for batch reduction in one session, it is best to alter the program to reduce the number of input statements. This alteration is best done by making the following 'define statements': right ascension and declination of the variable, comparison, and check stars; and Δ (B-V) for variable and check, respectively. These values remain constant from night to night, whereas the other input statements require variable data.

4. Summary

The complete reduction program runs to some 200 lines and can be executed by a small computer in a few seconds.

The program was written to be easily understood and was not intended to be as concise or elegant as possible.

Modifications to the program to permit real-time data analysis are now in progress.

A listing of the program and the terms used in it may be obtained by writing the authors at the following addresses:

Clifford Cunningham, 250 Frederick St., Apt. 101, Kitchener, Ontario, Canada;
Murray Kaitting, Tardis Observatory, 533 GlenForrest Blvd., Waterloo, Ontario, Canada.

REFERENCES

Crawford, D. L., Golson, J. C., and Landolt, A. U. 1971, Publ. Astron. Soc. Pacific 83, 652.

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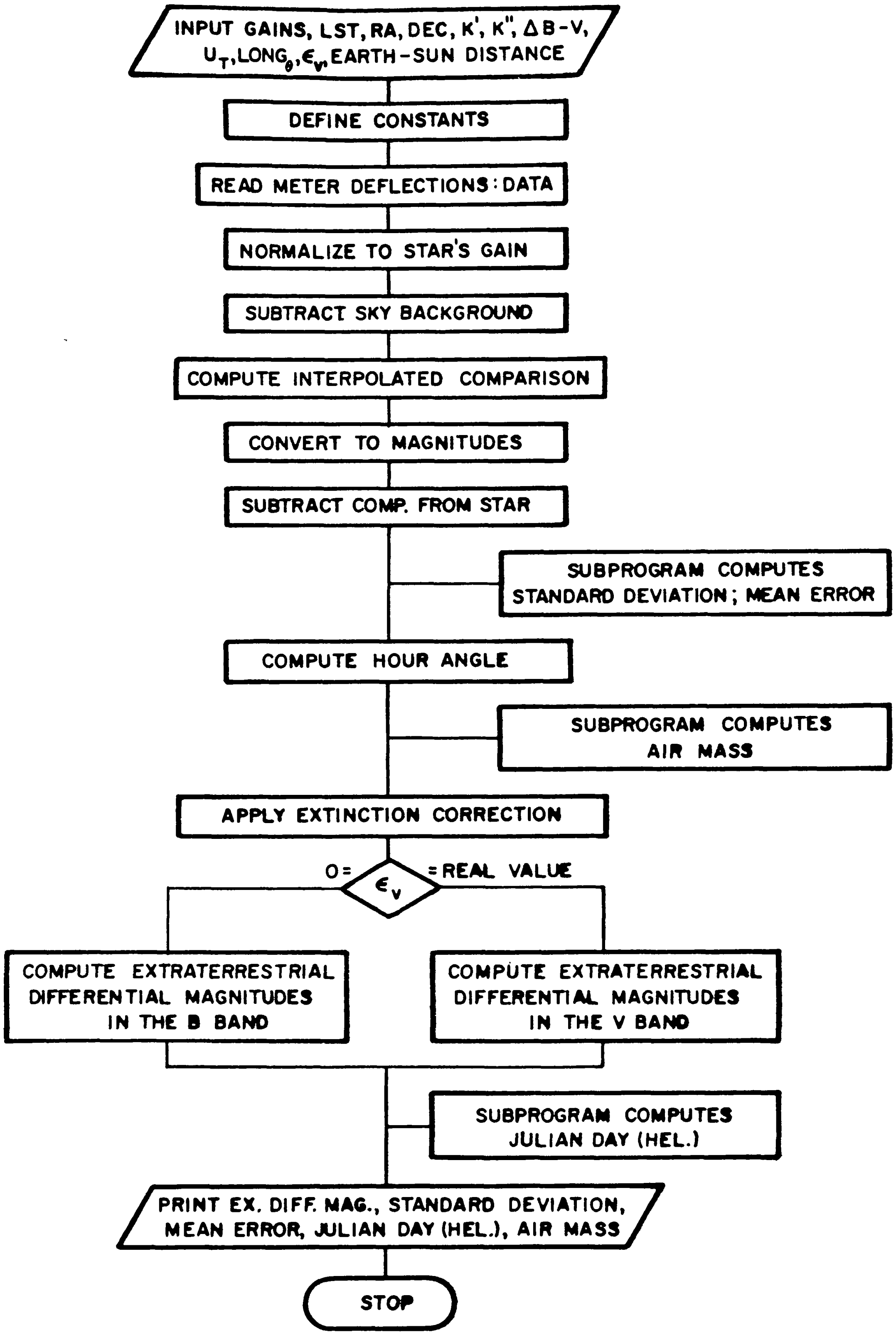

Figure 1. Flow chart of Photometric Reduction Program.

TABLE I

14 Aurigae
Input Data

Input data: 83, 42, 67, 42, 83, 43, 67, 43, 83, 43, 67, 43, 83, 42.
*(Insert two dummy values since there were no measurements taken on a check star): 83, 42.
Input: Gain of the star = 10^{-6}
Input: Gain of the comp = 10^{-6}
Input: Gain of the check = 10^{-6} (Dummy Value)
Input: Gain of the Sky = 10^{-7}
Sidereal time one = 4.25
Sidereal time two = 4.35
Sidereal time three = 4.67
RA of the star = 5.21
Dec of the star = 32.63
RA of comp = 5.23
Dec of comp = 33.32
RA of check = 5 (Dummy Values)
Dec of check = 32
K Prime = .19
K Double Prime = 0
Delta B-V = -1.05
Check B-V = -1 (Dummy Value)
Day = 13
Hour = 6
Minute = 14
Sun AU = .989504
Solar long one = 230.53
Solar long two = 231.53
EV = -.167

14 Aurigae
Output Data

V1 = .4209298503
V2 = .4219449989
V3 = .4225047835
Delta Average = .4218268776
Check = -.0029295627
Standard Deviation = .0008710457
Mean Error = .0005028984
Julian Day = 2444921.761

For K Determination:

Air Mass One = 1.037820483
Air Mass Two = 1.033766551
Air Mass Three = 1.029843979
-4.740626406
-4.739936831
-4.740626406