INTERNAL CALIBRATION OF ASTRONONOMICAL PHOTOGRAPHS

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ABSTRACT

By applying the principle that all stellar image profiles should be identical apart from a scale change, we can derive a relative calibration for a photographic plate without use of calibration spots or other indirect means.

1. INTRODUCTION

Despite the arrival in recent years of various forms of electronic two-dimensional detectors, photographic plates still have enormous advantages. For low cost they collect panoramic (~36 square degrees) data to faint limiting magnitude (~22). The serious drawbacks with photographs are their lack of dynamic range and a complex photometric response function. We describe here an improved version of the technique first presented in the Measuring Machines Workshop 1982 (Bunclark 1983) which partially solves the former problem and completely solves the latter. By requiring that the areal profile of a star be independent of its magnitude we can derive a "magnitude index" for stellar images which is linearly related to photoelectric magnitude over a range of up to 14 magnitudes. The linearity is reliable down to the plate limit and therefore also provides a means to extrapolate calibrating photoelectric sequences which typically end at around 17th magnitude. From the photoelectric sequence it is necessary to determine the slope and intercept of the calibration. We have developed the method specifically for use with SERC APM machine output, but it could be adapted to any data which provides profile information for large numbers of images in a field.

2. APM OUTPUT

The APM machine scans a given area of plate two times; the first pass divides it into 0.5mm x 0.5mm regions containing 64x64 pixels (or

M. Capaccioli (ed.), Astronomy with Schmidt-Type Telescopes, 147–154.

samples). A histogram is generated from these 4096 pixels and a modal estimate obtained which is taken to be the most likely background value. During the second pass, these background values spaced every 0.5 mm are interpolated to give a background estimate at every 7.5 micron sample position. A threshold above the local background is then subtracted from the sample value, and finally samples greater than zero are collated into images which are parameterised for output. The sixteen parameters are: integrated intensity, y-position, image number, x-position, 2nd x-moment, x-y cross moment, 2nd y moment, peak intensity, and an eight-level areal profile. Intensity/density output from APM has a range of 0-255. The profile of an image is sampled at eight levels set at threshold, t+1, t+2, t+4, t+8, t+16, t+32 and t+64. This logarithmic spacing measures the whole unsaturated part of bright images while providing sufficient sampling of faint ones.

3. PRINCIPLE OF THE INTERNAL CALIBRATION PROCEDURE

All stars are essentially point sources. The reason they appear as extended images is that they are smeared by atmospheric seeing, and the image suffers from scattering in the telescope optics and in the emulsion. These processes are independent of how bright the star is, so the final intensity distribution in the emulsion during exposure is identical for all point sources apart from a scale change. In actual fact since different parts of the field "see" a slightly different telescope geometry, there can be variations in image structure depending on position.

For a given image we have measures of the radius at some fixed levels above threshold. Suppose we had (i) a standard image whose profile was known at all points and (ii) the calibration curve so that we know the intensities of the levels at which the areal profiles are sampled. For a given image at a given level we know r and I(r), the intensity at that radius. Then read off the standard profile Io(r), and the luminosity of our image is

$$L = \frac{L_o \, I(r)}{I_o(r)} \qquad (1)$$

where Lo is the luminosity of the standard image. In fact, several profile measurements are always available, so several values of L can be computed, and averaged.

Further, if we know the brightness of all the stars and the standard profile we can derive the intensity of the levels (ie the calibration curve) by

$$I(r) = \frac{L \, I_o(r)}{L_o} \qquad (2)$$

or finally, knowing the calibration and the brightness, we can derive

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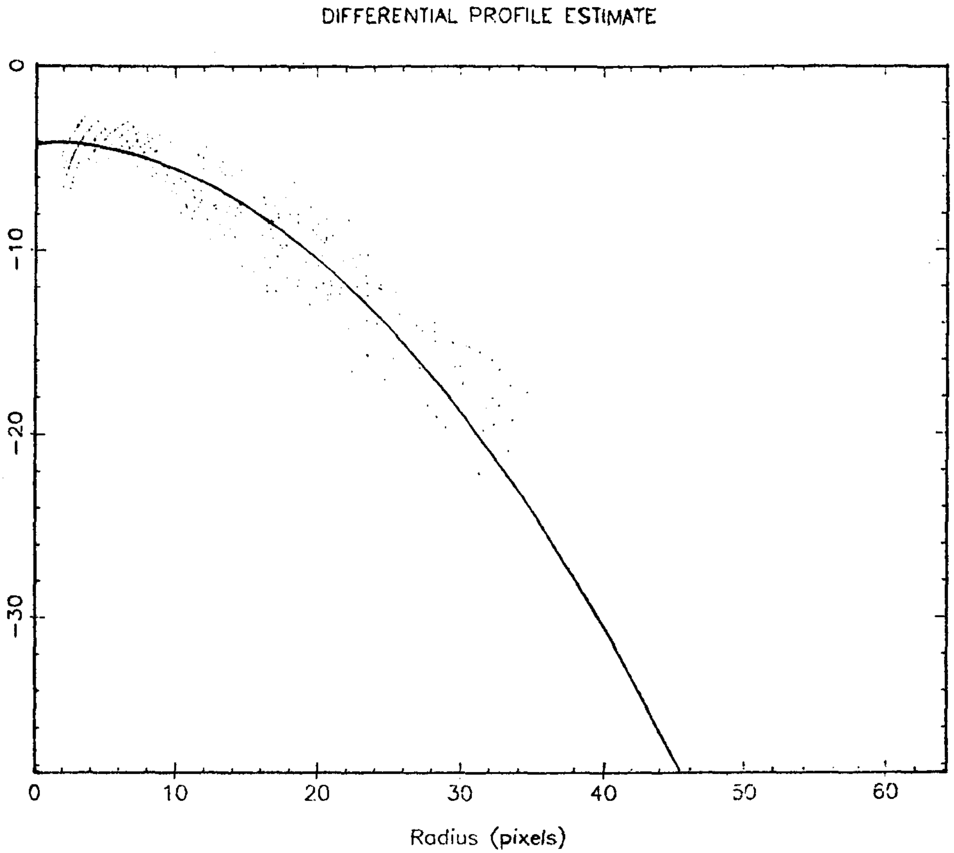

Figure 1. Inverse gradient of logarithmic profile used to generate initial profile estimate

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the standard profile from

$$Io(r) = \frac{Lo\ I(r)}{L} \qquad (3)$$

Of course in practice we know none of the elements, and in fact would like to determine them. The procedure is to obtain a good first estimate of the standard profile and of the calibration. Then the brightnesses of the stars are computed from (1), and better estimates of calibration and profile from (2) and (3). The three elements are iterated cyclically (typically about ten times) until no further convergence occurs.

4. GENERATION OF FIRST GUESSES

The iteration converges fairly weakly, and if seriously incorrect starting points are chosen the process will diverge to nonsense. To form the first estimates of the profile and the calibration curve, only data near sky are used. This is because for a small range of intensity the relationship between incident intensity and measured density is fairly linear, so the calibration curve for this region can be taken as a straight line with 45 degree slope. Secondly, it has been found that when the inverse of the gradient of the logarithmic intensity profile is plotted against radius, the result is well represented by a parabola (figure 1).

$$dr/d(logi) = a + br + cr^2 \qquad (4)$$

where a, b and c are empirically determined constants. Then the profile is given by

$$logi(R) = \int_0^R \frac{1}{a + br + cr^2}\, dr$$

$$= \frac{2}{sqrt(D)} \arctan\left(\frac{b + 2cR}{sqrt(D)}\right) + K \qquad (5)$$

where K is the constant of integration, and $D = 4ac - b^2$ (D positive). As we are not able to determine the zero point at this stage, K may be taken to be zero. Now it is possible to derive the preliminary calibration of all eight areal profile levels. From the data, it is found at which value of threshold radius the areal profile at a level goes to zero. The difference in log I between the two levels is then simply the difference in log I between the peak of the profile and the

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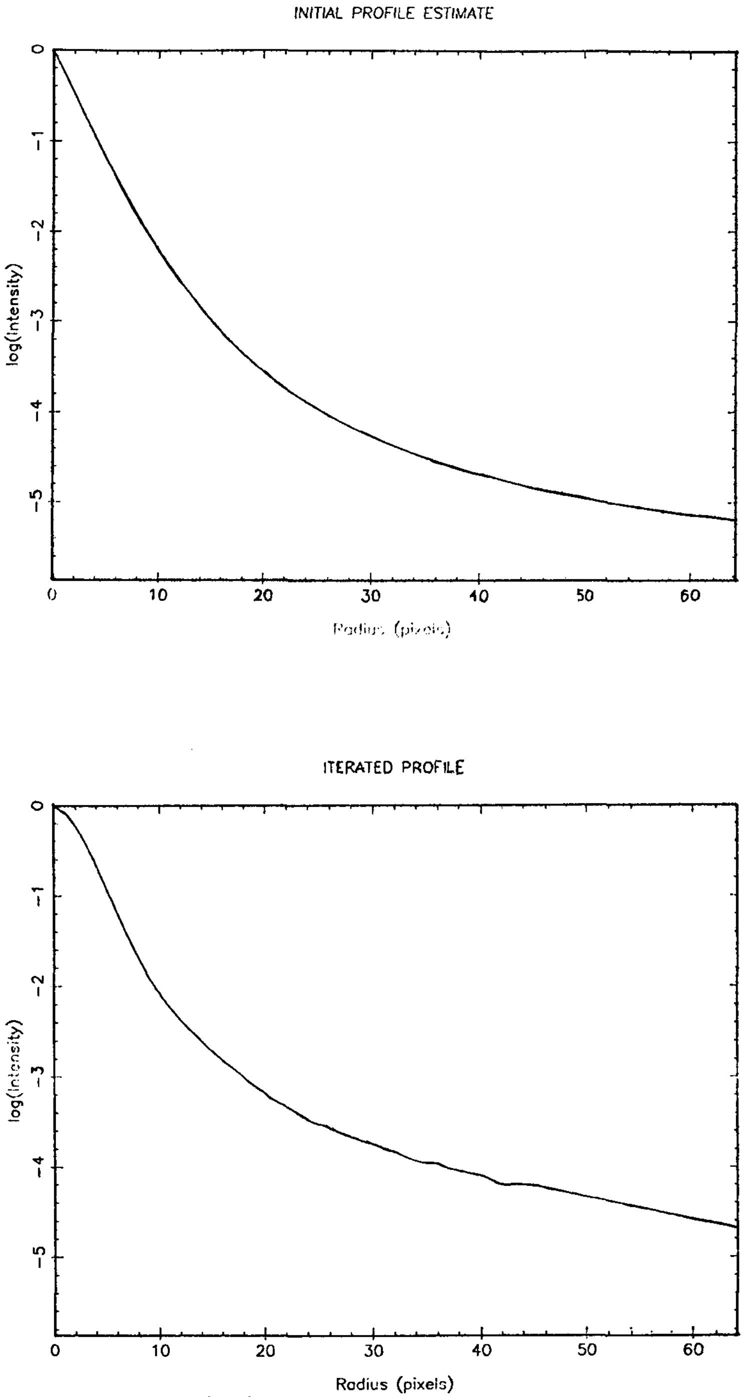

Figure 2. (Top) Initial profile estimate.
(Bottom) Final version of profile after iteration.

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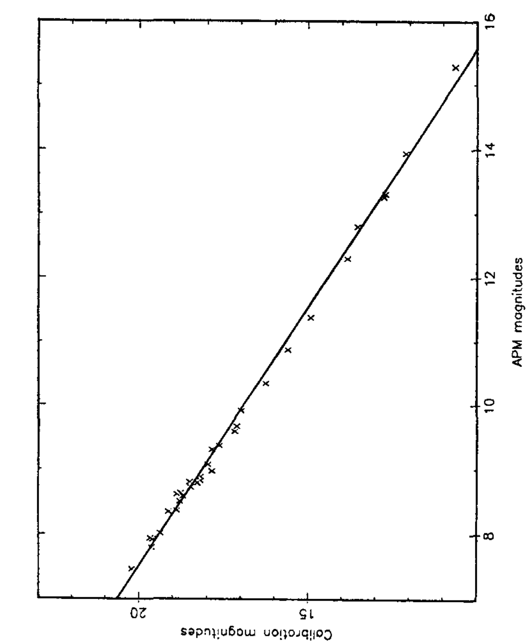

Figure 3(a) V7398 Fornax UKST.

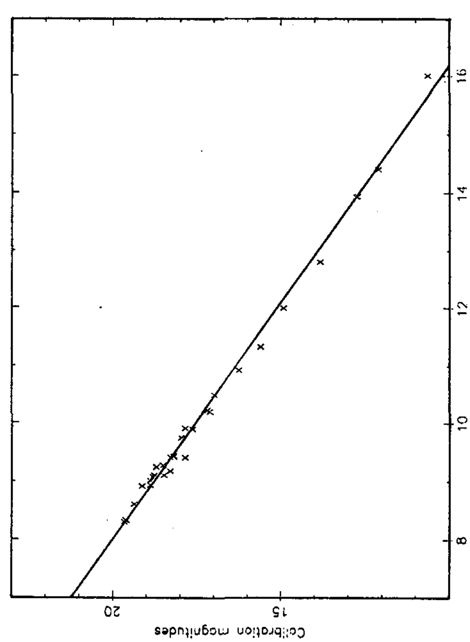

Figure 3(b) V 7151 Fornax UKST.

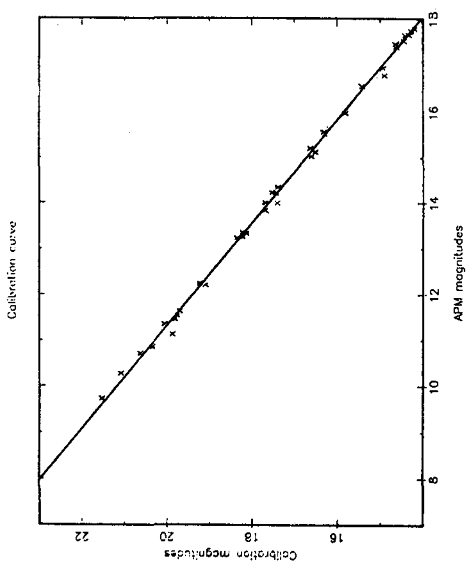

Figure 3(c) B plate, NGC 2403 CFHT.

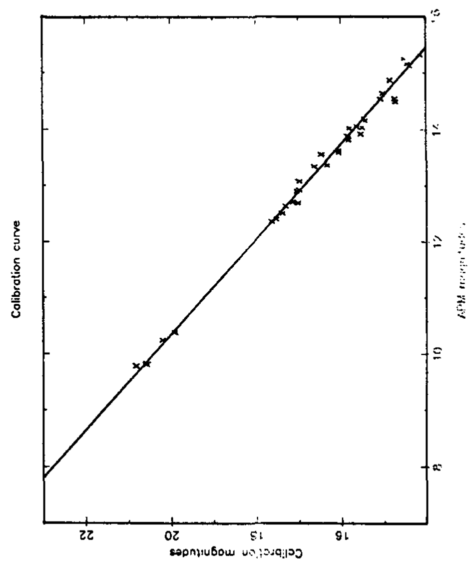

Figure 3(d) V plate, M33 CFHT.

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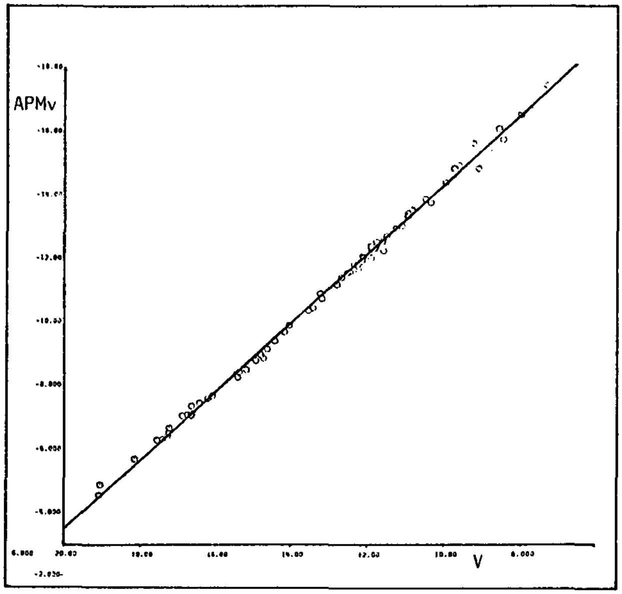

Figure 3(e) V plate, SGP UKST.

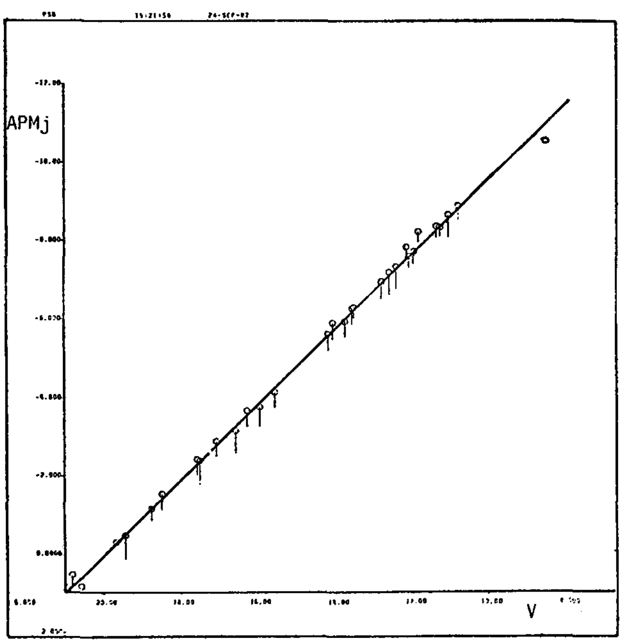

Figure 3(f) J plate, M31 PS.

value at the given threshold radius.

5. ITERATION

The iterative stage can now be entered, computing in turn "magnitudes" from profile and calibration, calibration from magnitudes and profile, then profile from magnitudes and calibration. The overall "shape" of the three sets of data are not much changed, but rather detail is added. Figure 2 shows a typical first estimate of profile from (5), and the final iterated profile. Finally the magnitude index is plotted against "APM magnitude", which is $-2.5\log(\Sigma D)$ for an image. This curve is used as the actual calibration, since the APM magnitude is less noisy than the magnitude index (the former is the sum of all points in an image, and the latter is computed from only a few samples of the image profile).

To achieve the final calibration, we must plot magnitude index against standard magnitudes for at least a few stars. This also serves to prove the method, and so several examples are shown in figure 3.

For stars, this calibration method is rigorous because stellar images define the solution and stellar sequences tie it to standard photometry. However, we also end with a calibration curve, and as all objects have an areal profile, it is possible to calculate isophotal magnitudes for extended objects by integration over their profile. A typical scan threshold puts the brightness of the outermost isophote at about 25 magnitudes per square arcsec. If desired, the integration may be stopped at a particular isophotal level (or extrapolated to one).

6. CONCLUSION

We have presented a method of calibrating astronomical photographs which does not require a deep sequence of standard stars. Further it does not use sensitometer spots which are notoriously unreliable. With the advent of measuring machines which routinely digitise whole plates, we feel this is the best possible way to carry out photographic calibration.

7. REFERENCE

Bunclark, P. S.: 1983, Proceedings of the Workshop on Astronomical Measuring Machines, Occasional Reports of the Royal Observatory, Edinburgh, No. 10, p149.

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