Pixel Addition: Pushing Schmidt Plates to B = 25

In the late 1970s when the COSMOS measuring machine was being developed at the Royal Observatory, Edinburgh, and there was the promise of large numbers of plates from the UK Schmidt telescope at Siding Spring, the idea of co-adding a set of plates to go very deep was already being discussed. At that time, several approaches seemed promising. Firstly, there was the idea of photographic addition, where plates are progressively projected onto a film thus increasing the signal-to-noise. A measuring machine is only used at the end to analyse the final images. This technique has been developed by D. Malin to give a significant improvement in limiting magnitude, but the method does have some major drawbacks. Because there is distortion between plates taken at different hour angles or different centres, the whole field cannot be worked at one time, and must be cut up into small pieces. This adds a huge logistic overhead both to the addition procedure and to subsequent analysis, where the pieces must be matched together. Another problem concerns scattering of light in the emulsion during the addition process which appears to make star-like images grow as in a normal photograph of a bright point source.

First thoughts in the early 1980s about a machine based approach to plate addition were limited by the small size of computer back-up storage available at that time, and concentrated on a real time addition of measures. This approach was never really practical, and progress had to await the introduction of cheap mass storage at the several Gbyte level. This has now happened and the project to add whole Schmidt plates digitally has become feasible. The area of a UK Schmidt plate which can comfortably be used without problems of vignetting etc. is about 25×25 cm^2. Scanned at a sampling interval of 16 μm, this comprises approximately 250 million pixels, or 500 Mbytes. For cumulative pixel addition sufficient disc space is required to store the current added data, the new measure, and the new total. This means at least 3×500 Mbyte arrays, or 1500 Mbyte. Given that a fair amount of working space is also needed, the total required is around 2000 Mbytes.

The programming approach for combining the data uses sequential access to all the files. This gives greater flexibility in the types of mass storage which can be used, and a very fast running code. An important feature of the procedure is a transformation from each master pixel to the nearest corresponding pixel in the new data. It was found in practice that in the test cases a simple rotation translation and scale transformation was sufficient, but provision was made for a more sophisticated transformation to be used should circumstances warrant it. Having transformed the master pixel to the coordinate frame of the new measure, the bulk of the programme is concerned with ensuring that the relevant part of the dataset is in core so that the appropriate value can be chosen to add to the master pixel.

So far, the programme has been tested in two ways. In the first instance, two whole plate mappings were added using a single rotation, translation and scale transformation. Fields in the corner were examined, and no detectable misalignment of the star images was observed. The plates were however well matched, being on the same centre and taken at similar hour angle, and so it may be necessary in general to use a more sophisticated transformation.

The second test involved adding a one square degree area from a large number of plates, in two colours. The area contained a deep CCD sequence to enable calibration of the measures and an estimate of the depth attained by the co-addition. COSMOS measures are output as transmission values, but the measurement is dominated by noise in the emulsion i.e. fluctuation in density, hence the transmission values were converted to photographic density before addition. Since on the 'straight' part of the characteristic curve emulsion noise is essentially constant, independent of density, this ensures the correct weighting of each pixel value. Figure 1 shows a grey scale plot of a survey quality IIIa-J UK Schmidt plate in an area containing the sequence. Figure 2 shows the same area after 12 plates have been added together; the increase in depth is obvious, and amounts to a little over one magnitude. Figure 3 shows the result of adding 58 IIIa-J plates, the total number of acceptable quality currently available in Field 287. Figure 4 shows the result of adding the 61 IIIa-F plates available in the field.

In order to study the quality of the addition programme, the relationship between the number N of plates used and the sky noise $\sigma_{\mathbf{sky}}$, the S/N ratio and the FWHM of the stellar images have been analysed by F. La Franca and L. Miller. They found that:

1. the decrease of the noise on the sky level is on average consistent with the relation $\sigma_{\mathbf{sky}} \propto \frac{1}{\sqrt{N}}$;
2. the increase of the S/N ratio in the stellar images is of the form $\mathrm{S/N} \propto \mathrm{N}^{\alpha}$, with $0.4 < \alpha < 0.5$;
3. the increase in the size of the images due to registration in the addition process is small, and tends to converge to values $< 10\%$ after 10 plates.

All these results are consistent with an increase in depth of the stacked plates of:

$$\Delta \mathrm{m} = 2.5 \log \mathrm{N}^{\alpha}, \quad \text{with} \quad 0.4 < \alpha < 0.5.$$

confirming that almost all the signal contained in each plate is transferred to the final co-added data.

In order to assess the depth, completeness, photometric accuracy and other properties of the co-added data, the COSMOS analyser was used in the ordinary way (with the image deblanding option) to detect and measure images in the field. These measures were calibrated using the CCD sequences, giving the calibration curve in Fig. 5. The number/magnitude relation for the field is shown in Fig. 6. From this it may be seen that for 58 plates, the completeness limit is about $\mathrm{B_J} = 24.0$. This corresponds to a B magnitude of about $\mathrm{B} = 24.5$ with images detected to $\mathrm{B} > 25$. The change of slope at around $\mathrm{B_J} = 22$ is due to the counts becoming dominated by galaxies which have a steeper slope than stars.

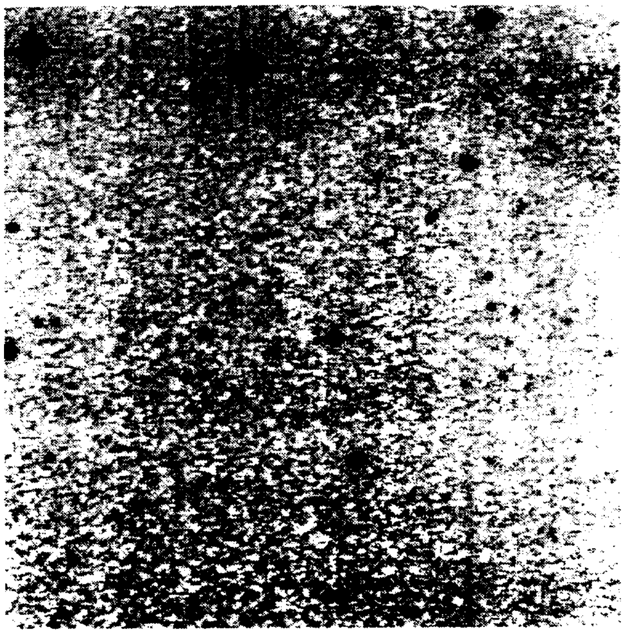

Figure 1.

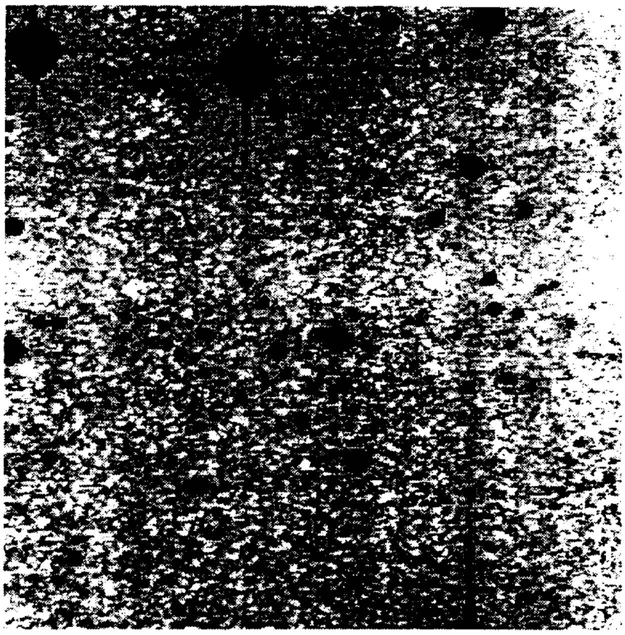

Figure 2.

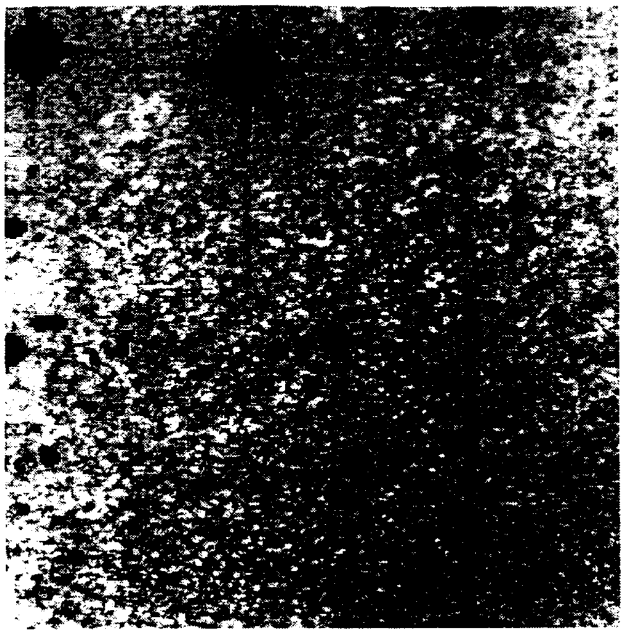

Figure 3.

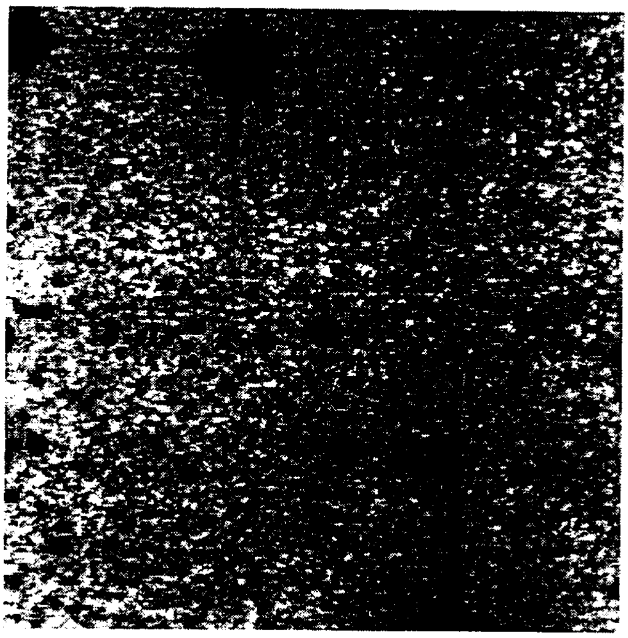

Figure 4.

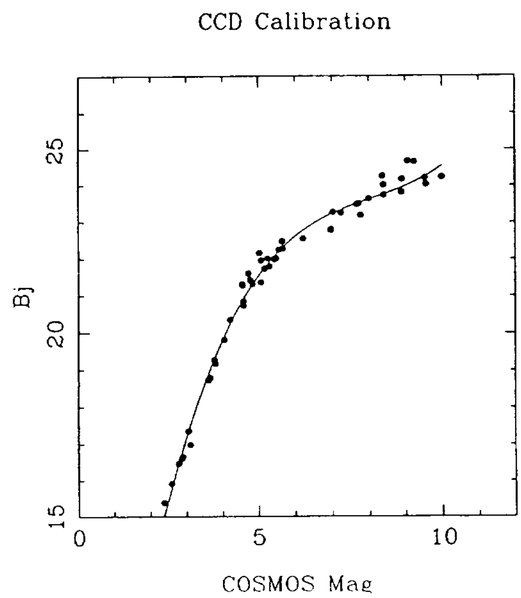

Figure 5.

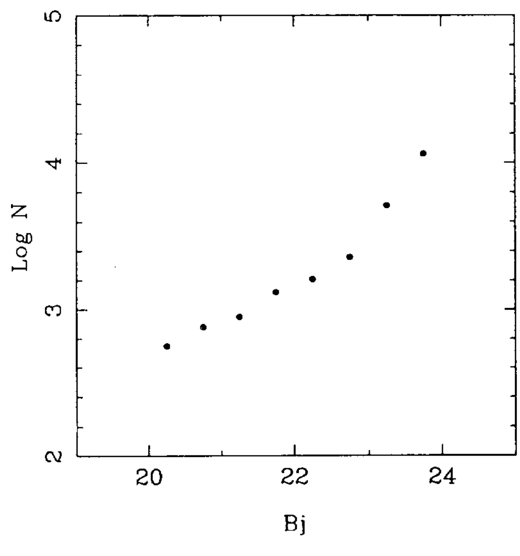

Figure 6.

The next step in this project is to add data for the full Schmidt plate area in the B and R colours discussed above, together with 30 I plate and 8 U plates. This should provide an unparalleled opportunity for a number of investigations which require great depth and wide angle coverage. These include the galaxy correlation function, the galaxy cluster distribution, searches for high redshift quasars and studies of the galactic halo. There are also many rare objects such as brown dwarfs and cool white dwarfs which should be detectable in the huge dataset which will result from co-addition of the full Schmidt area.

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