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Restoration of Digitized Astronomical Plates with the Pixon Method

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Abstract. We report applications of the Pixon Restoration Method to digitized plates of the Sonneberg Plate Archive – the world's 2nd largest. Results so far obtained show that the severe astigmatism/coma distortion present in the outer parts of the wide field images can be almost completely removed. Object definition (FHWM) of point sources and S/N also improve by factors of 2 to 7, depending on the object strength and location, background etc. We briefly address implications for the inclusion of digitized archives in the virtual observatory context.

1. Introduction

Sonneberg Observatory in the Thuringian forest is blessed with a night sky which is still almost free of light-pollution. It has been collecting photographic images of selected sky areas since about 1930 and since the 1950s this has been supplemented by imaging of the whole northern sky, in a systematic manner known as "Sky Patrol". The main purpose up to now has been the detection and study of variable stars. In order to transform this rich collection of photographic images into a form which is useful and accessible to the astronomical community, digitization of the plates was begun several years ago.

Many different telescopes, cameras and photographic emulsions have been used over the years to collect these data, each of them with its own peculiarities and shortcomings. In particular, we are dealing with wide angle astrophotography for which there is no comparison in the era of CCDs. The field size is about 4.3° for the Schmidt plates, 11° for astrograph plates, and 27° for the Sky Patrol plates. The latter, on which we shall concentrate here, suffer from severe astigmatism affecting more than 75% of the plate area. It is therefore obvious that the processing of the digitized data should include steps beyond the basic reduction of dark current subtraction and flat-fielding.

We report here on our attempts to roll back part of the image degradation that occurs between infalling starlight and the digitized plate, using the Pixon image deconvolution method, first described by Pina & Puetter (1993) and then further developed by others (e.g., Eke 2001).

2. Astronomical Aims

The information contained in the $\approx 275,000$ plates of our plate archive, collected over more than 70 years, is surely not yet fully exploited, although C. Hoffmeister and his co-workers have discovered over 10,000 variable stars on these plates, including very important objects such as HZ Her, FG Sge and BL Lac.

We are convinced that the data currently buried in our and the other existing archives deserve to be excavated and treated using modern methods of mass image processing. Since each plate of the Sky Patrol contains information on some 100,000 stars, such an effort would extend current surveys back by about 50 years down to the plate limits of $13^m - 14^m$. Not only are many more variable stars likely to be detected by an automated search, but topical questions such as the existence of sun-like cycles in stars, or simply the long term behaviour of "normal" stars, could also be attacked on a broad basis (Kroll 1999). To do this, we have to push the detection threshold and photometry to the limits.

3. Restoration

Image restoration in general is an inverse problem, where the blurry and distorted data is related to an undistorted image through an imaging model that describes all the degradations influencing the true underlying image. Our model includes the local blurring process, the nonlinearity of the photographic emulsion, the characteristics of the image scanner and a model for the noise. The scanner signal fluctuations are modelled as additive, plate specific, signal dependent, gaussian noise. The solution sought is considered to be the best explanation of the data. In image restoration, especially in the presence of noise, there is a set of solutions rather than a unique solution. Small fluctuations in the data due to noise lead to large-scale fluctuations in the solution set. This discrepancy between the number of degrees of freedom used in the restoration and the corrupted information in the data is usually called an "ill-posed problem". In addition to the data, further constraints must be imposed by "regularization".

The idea of regularization is to take all a-priori-information into account to select and weight the solutions in the set. This prior information is combined with the data and defines a best solution by trying to achieve smoothness and yet remain faithful to the data. The pixon method is an efficient way to regularize inverse problems. "Pixons" instead of image pixels are used to obtain the "simplest" solution that explains the data through the imaging model. Details of the theoretical basis and some practical implementations can be found in Pina & Puetter (1993), Puetter (1994) and Puetter (1996).

We use a fuzzy pixon basis to represent our solution E. In this "correlation" approach adjacent pixons share some of each other's signal instead of having hard boundaries. The unblurred image is described as the local convolution of a so called "pseudo-image" E^P containing the signal with a scale-dependent symmetric 2d-Gaussian pixon-kernel. The distribution of the local pixon sizes represents the model-part, P, of the image description. The goal of the restoration process is to determine a combined image-model-*pair*, in a nonlinear iterative manner. That task can be interpreted in terms of a Bayesian estimation scheme in which the solution sought maximizes the joint probability $p(E^P, P, \Omega, S^M)$:

$$E_{\vec{x}} = \sum_{\vec{y}} \hat{E}^{P}{}_{\vec{y}} \cdot \hat{P}(\delta_{\vec{x}})_{\vec{y}-\vec{x}} \quad : \quad \hat{E}^{P}, \hat{P} \rightarrow \max_{E^{P},P,\Omega} \left\{ \underbrace{p(E^{P},P,\Omega|S^{M})}_{\text{Maximum-A-Posteriori}} \propto \underbrace{p(S^{M}|E^{P},P,\Omega)}_{\text{Likelihood}} \cdot \underbrace{p(E^{P},P,\Omega)}_{\text{Prior}} \right\}$$

where

E represents the solution set $E: E_{\vec{x}} \mid \vec{x} \in N^2$

S^{M} represents the data set $S^{\mathrm{M}}: S^{\mathrm{M}}{}_{\vec{x}} \mid \vec{x} \in N^2$

Ω represents the set of regularization parameters $\Omega: \Omega_{\vec{x}} \mid \vec{x} \in N^2$

The image-model-pair is calculated in a modified version of the scheme introduced in Pina & Puetter (1993). Instead of calculating a pixon width distribution approximately, our procedure estimates a Bayesian model. Therefore a regularization is needed to weight the influences of the likelihood and prior terms on the solution. In addition, some ideas from other researchers in the field of pixon restoration are used, adapted and refined, such as a specific weight of the signal distribution with respect to the current distribution of pixon sizes (Eke 2001). The calculation of the cost functions and their derivatives is done mainly by FFT-convolutions, thus preserving the $n * log(n)$ scaling of the algorithm.

4. Results

The example to be discussed here comes from a Sky Patrol plate, exposed for 20 minutes close to the zenith on a very clear night in August 2000. The emulsion used was a Foma Astro Blue film without filter, sensitive to a wavelength range of about 420 − 520 nm. The example is based on a $1^{\circ} \times 1^{\circ}$ (294×294 pixel) section centered on M31 and also including M110. On the plate this section is located in the extreme corner with strongly astigmatic star images. For a larger field, north-west of κ Cas and closer to the optical axis and hence markedly less astigmatic, we only give some statistical results.

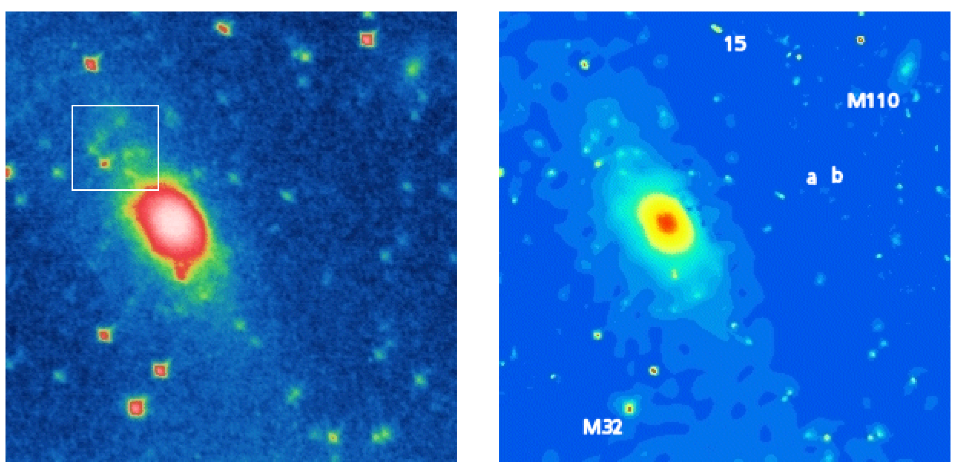

Figure 1. M31 field. North is at the top and west to the right. The original (dark current and flatfield corrected) is to the left and the restored form on the right.

Statistical Results: The automatic identifications of stars was based on the "find" procedure in the IDL Astronomy Library[1]. On the M31 field "find" found 38 (36) stars on the restored (original) image, for which the median FWHM is 1.8 (5.4) pixels and the median S/N-ratio is 15.9 (6.1). The corresponding figures for the κ Cas field are 747 (606) stars, 1.8 (3.4) pixel and 10.5 (3.0) for S/N respectively.

Individual Stars: Close doubles are well separated in the restored image. A limiting case is the pair marked "15". Here the original profile of the pair can hardly be distinguished from that of a single luminous star, whereas the restored profile shows a shoulder and has the maximum displaced by 1 pixel, indicating the distinction between the $9\overset{m}{.}6$ star PPM43223 and its $11\overset{m}{.}2$ NE companion.

The non-stellarity of M32 appears more pronounced in the restored image than in the original data. If the excess of the FWHM of M32 over the median of the sample stars is expressed in units of the mean absolute deviation from the median, this excess is 1.5 times larger in the restored image than in the original data although the M32-FWHM itself is a factor of 3.5 smaller. The galaxy shape of M110 also comes out much more clearly in the restored image. Finally, there are a number of stars which can only be evaluated photometrically in the restored image, e.g., the "boxed" group on the NE ridge of M31, and it shows some real stars (e.g., "a", "b"), which one would not have guessed the existence of from the original.

5. Further Prospects

We identify the following tasks for future work: to implement semi-automatic extraction of a PSF valid for a particular plate region, and to reduce the run time (e.g., tiling, parallelizing). We also note that restoration near the edge, and also more centrally, stops at a FWHM of $\approx$ 2 pixels, very close to the minimum allowed by the sampling theorem. The connection between sampling and the pixon method seems worth exploring further. Finally, astrometry and photometry with the restored image have to be tested more thoroughly.

We consider it essential to make digitized plate archives—the work of generations of observers—accessible in the virtual observatories to come. From our results we conclude that somewhere in the query chain a web-based (pixon) deconvolution tool should be available.

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[1] `http://idlastro.gsfc.nasa.gov`