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Restoration of Digitzed Astronomical Plates with the Pixon Method

Peter R. Hiltner, Peter Kroll

Sonneberg Observatory, Sternwartestr. 32, D-96515 Sonneberg

Rico Nestler, Karl-Heinz Franke

Technical University of Ilmenau, Faculty of Computer Science and Automation, Computer Graphics Program, POB 100565, D-98684 Ilmenau, Email: rico.nestler@tu-ilmenau.de

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

1. Introduction

Sonneberg Observatory in the Thuringian forest, blessed with a still scarcely light-polluted night sky, is collecting photographic sky images of selected sky areas since about 1930, and since the 1950's also of the whole northern sky, in a systematic fashion named "Sky Patrol". The main purpose hitherto has been the detection and study of variable stars. In order to transform the rich collection of astronomical plates to a form which is useful and accessible to the astronomical community, digitization of the plates was begun several years ago.

Quite a lot of 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 which is without comparison in the era of CCDs: about 4.3° field size 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. Thus it is obvious that the digitization process should include steps beyond the basic reduction of dark current subtraction and flat-fielding.

We want to report here on attempts to roll back part of the image degradation which occurs in the pipeline from infalling starlight to the digitized plate, using the Pixon image deconvolution method, first described by Pina & Puetter (1993) and then further developed also 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, albeit C. Hoffmeister and his co-workers have discovered on these plates over 10,000 variable stars (among them 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 being excavated and treated with 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 (within the magnitude limit of $13^m - 14^m$) of current surveys back by about 50 years. Not only are much more variable stars likely to be detected by an automated search, but also topical questions like the existence of sun-like cycles in stars, or simply the long term behaviour of "normal" stars, could 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 gets related to an undistorted image through an imaging model, which explains all the degradations influencing the true underlying image. Our model includes the local blurring process, the nonlinearity of the emulsion, the characteristics of the image scanner and a model for the observational noise. The scanner signal fluctuations are modelled as additive, plate specifically signal dependent, gaussian noise. The solution sought is referred to as the best explanation of the data. In image restoration, especially in the presence of noise, there is rather a set of solutions than an 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 coined an "ill-posed problem". In addition to the data, constraints must be given by "regularization".

The idea of regularization approaches is to take all a-priori-information into account to select and weigh 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 on 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 $p(E^P, P, \Omega, S^M)$:

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

where

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

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

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 approximately calculating a pixon width distribution, our procedure estimates a Bayesian model. Therefore a regularization is needed to weigh the influences of the likelihood- and prior-term 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 stems from a Sky Patrol plate, exposed for 20 min close to the zenith in a very clear August night 2 years ago. The emulsion used was a Foma Astro Blue film without filter, sensitive to a wavelength range of about 420 - 520 nm. The example contains a $1° \times 1°$ (294×294 pixel) section centered on M31 and comprising also M110. On the plate this section is located in the very corner with strongly astigmatic star images. For a larger field, northwest of κ Cas, more central to the optical axis and markedly less astigmatic, we only give some statistical results.

Statistical results: The automatic identifications of stars were based on the "find"-procedure of the IDL-AstroLibrary (http://idlastro.gsfc.nasa.gov). On the M31 field "find" found 38 (36) stars on the restored (original) image, for which the median FWHM is 1.8 (5.4) pixel 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.

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 $9.^{\text{m}}6$ star PPM43223 and its $11.^{\text{m}}2$ NE companion.

The non-stellarity of M32 appears more pronounced in the restored image than in the original data: expressing the excess of the FWHM of M32 over the

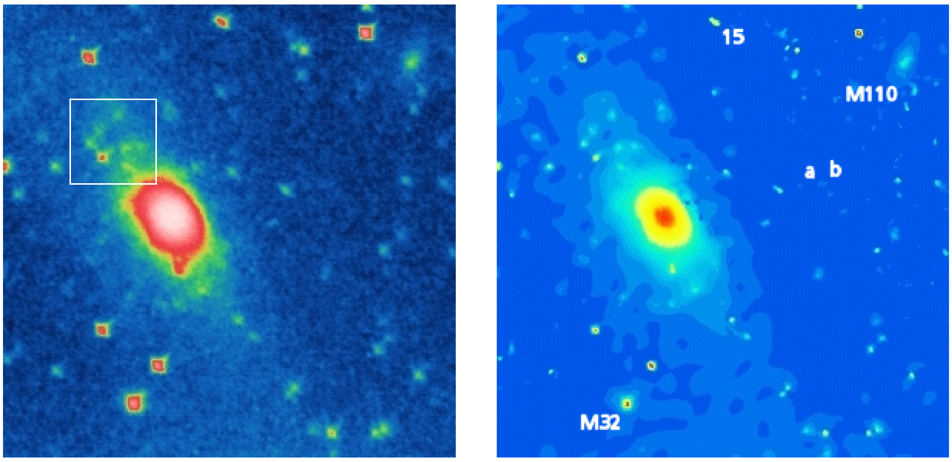

Figure 1. M31 field. North is on top and east to the right. Left the original (dark current and flatfield corrected), right the restored form.

median of the sample stars in units of the mean absolute deviation from the median, this excess is in the restored image 1.5 times larger than in the original data (the M32-FWHM itself being a factor of 3.5 smaller). The galaxy shape of M110 comes out much more clearly in the restored image, too. Finally, in the restored image there is a number of stars which can be evaluated photometrically only here (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 from the original.

5. Further prospects

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

We consider it a must 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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