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A METHOD FOR ENHANCED IMAGE PROCESSING AND SEARCH FOR VARIABLE STARS

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Abstract. The purpose of this report is to explain an enhancement in the standard procedure of processing signals extracted from astronomical images. We tested the method in confirmations of the transits of exoplanets Tres 2b and Tres 3b. We also found suspects of the variability of two stars: 3UC 317-048727 and TYC 3549-2704-1.

1. INTRODUCTION

There are well known problems related to imaging used in astrophotography. For example, images taken with ground based telescopes are subject to the blurring effect of atmospheric turbulence. Another one is coming from the errors arising from the use of equipment such as:

- dark and readout signals generated by CCD cameras,
- vignetting and
- uneven field illumination created by dust or smudges in the optical system.

On the other hand, many astronomical imaging programs require higher resolution than is possible without some correction of the images. All these problems are multiplied if modest equipment is used. Of course, there are many methods used in post processing. It should be noted that these procedures are in fact mathematical algorithms applied on digitized, numerical data representing extracted signals. There are also preprocessing procedures applied on the series of astronomical photographs such as photo stacking, and they are mostly based on physical enhancement of the signal such as the strength of the signal by accumulating it from a group of photos. As far as we know this procedure is used mainly for production of final images, therefore not for a dynamic analysis of a time process related to the series of photos.

Our method is the mixture of these two approaches. For a given set of photos representing a time process such as the variability of a star, we build a list of groups of images. Groups are built in a certain pattern in order to preserve the physical characteristics of the time process, its strength, shape and periodicity. We implemented special software for building the list of groups of photos concordant to the prescribed pattern. Then each group is preprocessed by stacking photos in this group.

In this way we averaged the signal strength, significantly reduced the noise coming from atmosphere turbulence, and eliminated errors generated by the used equipment.

At this stage we used the software DeepSkyStacker for processing the groups of images. So obtained, the new series of frames is then the subject to the analysis of the original time process, such as the star variability. At this stage we used software MaximDL and Peranso. A much better resolution of data and the curve representing the variability of the star is achieved compared to the data and the graph obtained by direct numerical analysis without the described preprocessing. In this way we confirmed transits of two exoplanets Tres 2b and Tres 3b. We also found suspects of the variability of two stars; they are 3UC 317-048727 and TYC 3549-2704-1.

2. LUCKY IMAGING

For better understanding of our procedure, we give a brief explanation of the method known as *lucky imaging*. Lucky imaging is a remarkably effective technique for delivering near-diffraction-limited imaging on ground-based telescopes. The basic principle is that the atmospheric turbulence that normally limits the resolution of ground-based observations is a statistical process. If images are taken fast enough (at least less than 0.1 sec) to freeze the motion caused by the turbulence we find that a significant number of frames are very sharp indeed where the statistical fluctuations are minimal. Imaging through atmospheric turbulence is a random process, and there is a small probability that any one image will be perfect, i.e. limited only by diffraction. In 1966 R. Hufnagel (1966, 1989) gave an estimate of this probability based upon the statistical properties of the speckles formed within a point image. He predicted that, for large diameter systems, the probability of a good exposure would vary as e^{-D^2}, D is the telescope aperture. So, telescopes with smaller D have greater probability to obtain good image. This result was confirmed by D. Fried in 1978. In 1981 D. Bensimon et al measured the probability of lucky imaging and verified this probability.

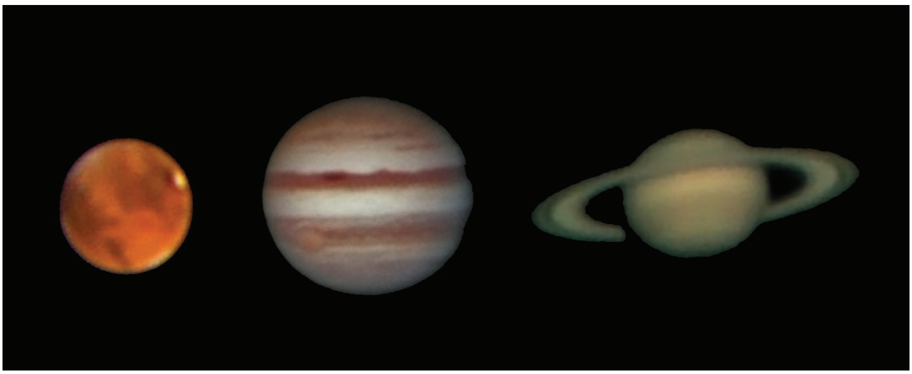

Figure 1: Images of planets obtained by lucky imaging.

By combining (stacking) these sharp images we can produce a much better one than is normally possible from the ground. We have routinely taken images of 1 arcsec resolution on the 12 cm refractor. Better results can be obtained with the assistance of adaptive optics system These principles have been used quite extensively by the amateur astronomy community who has been able to take very high quality images of bright objects such as Jupiter and the other planets. Recently this method became of interest in professional astronomy too, see for example doctoral dissertations of N. M. Law (2007) and A. Pál (2009), and the paper by Zhang et all (2011).

In Figure 1 images of Mars, Jupiter and Jupiter are presented that we made by the lucky imaging method. These photos were obtained in April 2012. Each photo is produced from the choice of about 800 best frames selected from 1000 raw frames. One can see that the theoretical resolution limit of 1 arscec for our instrument (see below) is achieved.

3. ALGORITHM

Suppose that there are n astro-images $S_1, S_2, , S_n$. The idea is to divide these exposures into k equal groups $G_1, G_2, \ldots, G_k$, each group G_i having m consecutive images. Further, if G_i and G_{i+1} are successive groups, then the first exposure S_p in G_i has the lower index then the first exposure S_q in G_{i+1}, i.e. $p < q$. Finally, the groups G_i and G_{i+1} may overlap, and in fact in most cases we make the sequence of overlapping groups. The number Δ of images contained in the intersections of G_i and G_{i+1} is called the offset. We suppose that any two consecutive groups have the same offset.

After such a grouping of images of the sequence $S_1, S_2, , S_n$, we apply the standard preprocessing procedure (adding dark, bias and flat frames) on each group G_i and then stack all frames in G_i. In that way we produce the new sequence $P_1, P_2, \ldots, P_k$ of images. So obtained images P_i are called block frames. In this way we eliminated to the highest extent all imperfections of the equipment (dead pixels of the camera, electronic obstructions and vignetting), but also, due to the stacking, the blurring effect of atmospheric turbulence is lowered. Finally, the signal that we measured (such as the variability of the stellar magnitude) is multiplied i.e. it is strengthen.

In this way even with a modest astronomical cameras (and not so expensive), including commercial DSLR cameras, attractive results can be achieved, comparable to those obtained by professional (and expensive) astronomical cameras. Of course, sam stages in the described procedure can be omitted if the professional cameras are used, e.g. the application of dark frames. However, the stacking would enhance to the great extent even the measurements done with professional astronomical cameras.

It should be mentioned that the offset Δ plays here the important role. For greater Δ blocks G_i are more overlapping, so the length k of the new sequence P_i is more close to the length of the basic sequence of raw images. The drawback of large Δ is that then more computation is needed.

Once we have the new and "clean" sequence of frames $P_1, P_2, \ldots, P_k$, now containing the strengthen signal, one can proceed the intended analysis of the physical process (such as the variation of the stellar magnitude) represented by this signal.

To summarize, here are some basic properties of the sequence of groups G_i:

- Each individual group G_i contains the same number of images, say m.
- Each S_i (except several those at the beginning and the end of the sequence S_i) is covered by the same number of groups.
- Each group G_i has the constant increment Δ in the series $S_1, S_2, \ldots, S_n$.
- For the fictive exposure time of the image P_i it is taken the arithmetic mean of the exposure times of images in the group G_i.

As already said, the series of block frames $P_1, P_2, \ldots, P_k$ represents, for example, the change in time of the brightness of a star and it is the subject of the appropriate analysis (statistical or astrophysical). The first author wrote a FORTRAN program FL77 for dividing the series $S_1, S_2, , S_n$ into groups $G_1, G_2, \ldots, G_k$. The working pipeline of our procedure is summarized in Figure 2. (adaptation from Zhang et all, 2011).

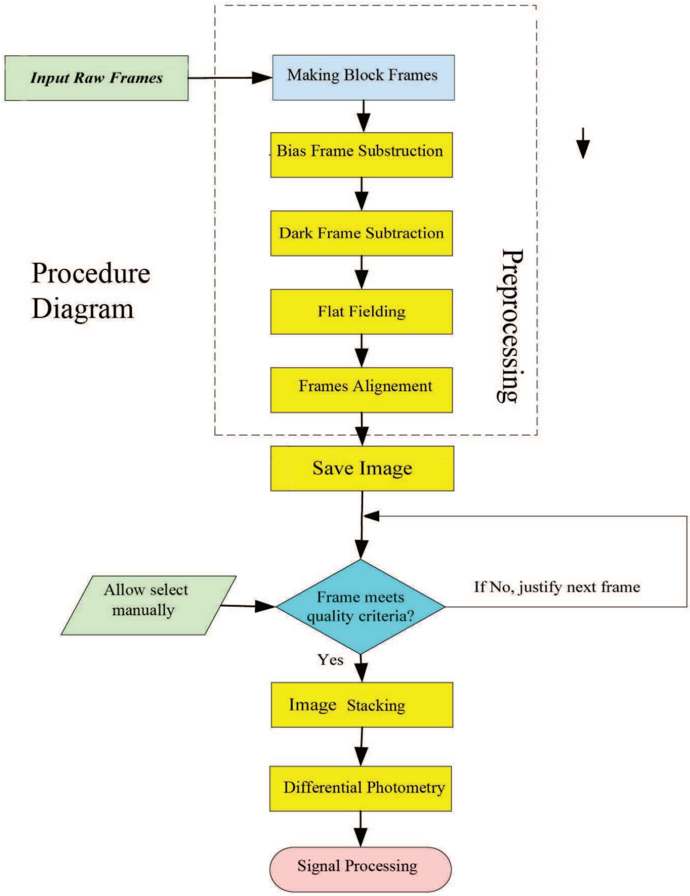

Figure 2: Flowchart of the procedure.

Blue rectangle in diagram denoted by "Making Block Frames" represents our procedure in the production process of stacked images. As seen, this is the first stage and a part of preprocessing procedure, before the images are available for further analysis.

Here is the good choice of constants for given n, the length of the series S_i: the number of groups $k = \sqrt{n}$, the offset $\Delta = k/2$, or $\Delta = n^{1/3}$. One can show that in the limit case, i.e. when n tends to infinity, the signal represented by $P_1, P_2, \ldots, P_k$ coincides with the signal obtained by ideal measurement. Particularly interesting applications is the use of lucky imaging in the analysis of processes that change in time, such as photometry, study of variable stars and search for exoplanets. New and cheap video cameras that are very sensitive to low light (such as Astrovid) based on L3CCD technology would play the crucial role in such projects.

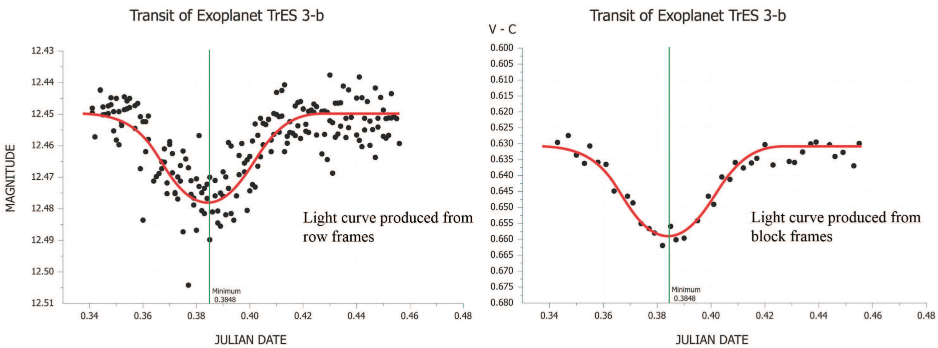

Figure 3: Transit of exoplanet Tres 3b.

As an example, we applied our method to find the light curve of the transit of the exoplanet Tres 3b in Hercules. We used a popular method for the study of variable stars, particularly short-term variables, the technique known as "differential photometry". Instead of measuring the magnitude of a variable star on an absolute scale, measurements are made over time relative to one or more non-variable stars in the field of an image and these differences are then plotted to show relative or differential change in magnitude. In Figure 3, each dot represents the magnitude of the parent star over which the exoplanet crosses. These magnitudes were measured from the corresponding frames by use of differential photometry. The light curve of the transit process is made by best fits method. The left hand graph (light curve) is produced from raw images (230 of them), while the right hand graph is made from block frames. Each block frame was obtained by stacking six consecutive raw frames. We have chosen the offset $\Delta = 0$. As seen, data are very well smoothed. While on the left diagram the measure points are widely scattered, on the right diagram they are very close to the light curve.

4. EQUIPMENT

In testing our procedure we used the following equipment:

1 Equinox 120ED APO 120mm $f/7.5$ fluorite apochromatic refractor.

2 Computerized Sky-Watcher NEQ6 PRO SynScan (EQ6 PRO): Equatorial mount with computerized GOTO system.

3 Computerized auto-guiding system with the supplementary guiding telescope of the aperture 90mm. Includes Opticstar PL-130M COOLAIR air-cooled, 1.3 mega-pixel monochrome video camera that connects to the computer's USB 2.0 port and can stream and store full resolution video at 12 frames per second (20fps at 640x480).

4 Canon EOS 50D photo camera.

References

Hufnagel, R. E.: 1966, *Restoration of Atmospherically Degraded Images*, National Academy of Sciences - National Research Council, Washington D.C. **3**, App. 2, 11.

Hufnagel, R. E.: 1989, *The Probability of Lucky Exposure*, The Perkin-Elmer Corporation, Technical Memorandum.

Fried, D. L.: 1978, Probability of getting a lucky short-exposure image through turbulence, *J. Opt. Soc. Am*, **68**, 1851.

Bensimon, D., Englander, A., Karoubi, R., Weiss, M.: 1981, Measurement of the probability of getting a lucky short exposure image through turbulence, *J. Opt. Soc. Am*, **71**, No.9, 1138.

Law, N. M..: 2007, *Lucky Imaging: Diffraction – Limited Astronomy; From the Ground in the Visible*, PhD Dissertation, Inst. Astron. & Selwyn College, Cambridge Univ.

Pál, A.: 2009, *Tools for discovering and characterizing extrasolar planets*, PhD Dissertation, Loránd Eötvös University, Faculty of Sciences PhD School of Physics.

Zhang, S., Zhao, J., Wang, J.: 2011, *An Efficient Lucky Imaging System for Astronomical Image Restoration*, 2011 AMOS Conference technical papers, 8p. (www.amostech.com/TechnicalPapers/2011.cfm)