Contrib. Astron. Obs. Skalnaté Pleso **47**, 133 – 136, (2017)

Prototype pipeline to search for variable stars in the Ondřejov D50 archive

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Received: May 26, 2017; Accepted: June 7, 2017

Abstract. We present our approach to search for new variable stars in archival data of the D50 telescope. The pipeline uses a maximum variance method combined with a minimum path criteria to eliminate false positives. Both single-night and multi-night approaches are tested. The method clearly identified twelve variable stars in the two testing fields. While newly identified variable stars are still in the process of classification, as an example we present the observation of a Mira Ceti type star V1286 Cyg, which the system "discovered" without prior knowledge.

Key words: Variable stars – Photometry

1. Motivation

Since 2007, the 0.5m telescope D50 in Ondřejov (Nekola et al., 2010), has been performing a sky monitoring programme related to activity of cataclysmic variable stars. The resulting images are stored in an archive, which has been made available to the authors in order to try and identify unknown variable stars.

2. Objectives

We decided to implement in Python (van Rossum, 1998) a pipeline which would not depend on prior knowledge of stars (from some catalogue) and which would identify variable stars solely upon observed variability within the dataset.

As a testbed, two datasets have been chosen, both in R-band, to avoid color effects. First is the photometric field 01111 containing the Gaia-discovered lensing event Gaia16aye (Bakis et al., 2016), a series which covers ~ 4 months with single images per night, the dataset consisted of 326 images, each containing typically 5000 objects. The other testing field 11107 pointed to V1333 Aql, covers a single night with moderately fast photometry ($\sim$ 4 images/minute) and contains 627 images, with 4000 stars each.

The archive tools of the D50 provide access to dark and flat-field corrected images. Sextractor (Bertin & Arnouts, 1996) is then used to create object lists which serve as the sole input to the pipeline.

3. Implementation

The pipeline is implemented in Python (+Numpy +Kapteyn (Terlouw & Vogelaar, 2015) packages) and consists of three steps:

Catalogue creation For each image file an object list is generated. We identify objects across these object lists based only on position. The prototype software uses a fixed spatial identification limit, which causes two related problems: a single object may be listed multiple times in the catalog with slightly different astrometry, thus appearing to be multiple distinct sources; alternatively, two adjacent, physically distinct objects may be falsely identified as one. A separate problem is due to variation in seeing, which may cause two nearby objects to appear as distinct sources on images with better seeing and as a single source in worse-seeing images. These problems pose a challenge to be met in the future, but as a great majority of objects do not suffer from them, we may approximate with the fixed limit simplification and proceed to the next step. A more careful approach may resolve an important fraction of these misidentifications. For example, after photometric zeropoints are computed, it would be possible to do a second pass, which would include brightness as an identification parameter, thus further improving the process.

Zeropoint fitting We decided to avoid the most straightforward idea consisting of calibrating the images with arbitrarily chosen secondary standard stars mostly because the standards are not available for all the fields. This way, also, the problem does not require any standards to be used: a cross-correlation of image photometries may be used instead to search for relative zeropoint of the images. The fitting is therefore done as an amoeba fitting, where the minimized criterion is total flatness of all star photometric lightcurves. To avoid the influence of variable stars, a robust estimator – median in our prototype case – is being used. The output of this step is a zeropoint for each image involved in the dataset. We are considering the inclusion of a color parameter for each star of the catalogue, to account for the Forbes effect (brightness change due to changing airmass), and possibly some more stable minimizing estimator (although the testing datasets fit well). This is the slowest step of the pipeline.

Variability estimation Once the zeropoints are found, we evaluate the mean and variance of residuals for each star. This variance is generally believed to be a variability tracer. There is, however, a problem related to neighbours – a catalogue entry may represent one, the other, both and/or a sum of two close objects. The resulting lightcurve would then present two or more stable levels, and not a smooth lightcurve (dual personality, bimo). We therefore compute another variability estimator, "bimo", by computing an error weighted length of the lightcurve in the magnitude space. We sort the objects by ratio of these two parameters (variance/bimo), and see the variable stars among those having the highest values.

4. Results - V1268 Cygni

In the dataset of the gravitational lens Gaia16aye, the pipeline discovered several variable stars. As an example, we present a known variable star V1268 Cygni, which the software found without its prior knowledge. V1268 Cygni's identification number in our system is 01111-822 and the pipeline returns the following coordinates:

$$19^h39^m31.708^s \quad +30^\circ11'39.5'' \quad \text{(J2000)}.$$

Here we present the star's lightcurve as seen in our dataset.

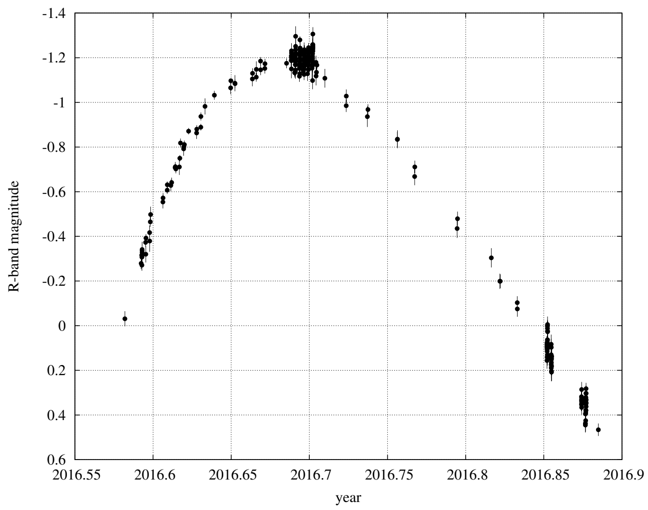

Figure 1. Light-curve of V1268 Cyg (discovered independently as 01111-822) as seen by D50 in Ondřejov.

5. Conclusions

We presented a prototype of a variable star detection pipeline. We tested it on the data from D50 telescope. The system is quite reliable and identifies new variable stars - as a demonstration, we detected V1268 Cygni.

Acknowledgements. We would like to thank Otevřená Věda for funding this project.

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