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Pole searching algorithm for Wide-field all-sky image analyzing monitoring system

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Abstract. Paper show how to find coordinates of the celestial pole. The algorithm is useful as the first hint for blind astrometry in order to help or speed up the process. The algorithm uses a principle of Hough transformation commonly used in computer vision.
Key words: Astrometry – Wide-field – All-sky

1. Introduction

Modern robotic telescopes are equipped with many types of sensors for environment monitoring to run autonomously. One type of the monitoring system is a weather estimation that can be done by imaging of the sky for a real-time view of the weather conditions. A popular way of monitoring the sky is using wide-field lenses with a proper digital detector. But such a wide-field system can be used not only for weather monitoring but also directly for some astronomical observations. One of the main demands is proper astrometric calibration of image, so further analysis can be made. In this cases, astrometric calibration of all-sky images is particularly difficult because of extreme distortion of image shape. The second problem is that most of the algorithms cannot find an astrometric solution simply because, they are not intended for systems using a fish-eye lens. Some algorithms are capable make a blind astrometric solution with no additional data about the image, but this can lead to very long processing time or even to failure of calibration. Therefore, some hint is useful. Our proposed method can locate approximate location of the north or south pole without any additional information and speed up the calibration process. In this paper, we describe a typical system for which our method is designed. Basic principles of our algorithm are presented, along with discussion of its precision and possible ways to further improve the reliability of results.

2. WILLIAM system

The project WILLIAM (Wide-field all-sky image analysing monitoring system) was first developed on demand to provide autonomous control of the telescope and observatory dome. The system is built as a low-cost wide-field and high resolution camera system. Main part of the system is a digital camera Nikon D5100 with APS-C chip (23.6 x 15.6mm) with resolution 4928 x 3264 pixels. The camera is equipped with fisheye lens Sigma 10mm F2.8 EX DC2. This lens covers most of the sky with an 180 diagonal view angle (corners of the image are at the horizon).The camera is controlled by RaspberryPi microcomputer. It controls parameters of the exposure depending on the day time and transfers acquired data to a dedicated remote virtual server to store and to process the data. The camera is located in a camera dome (usually used for surveillance applications) where an autonomous heating system is also located. The driving microcomputer is located near the dome in an another case with electric supply. More information about the system are in Janout et al. (2015).

3. Algorithm

Images used for testing were obtained by WILLIAM and debayered by Photoshop algorithm so maximum information is preserved. For comparison purposes, longer exposures were simulated by rotating images around north pole pixel. Three test images simulates exposures ranging from 20 seconds (original) and 26 to 32 seconds respectively (simulated). For testing, only the green channel was selected as it has least noise and chromatic aberration.

Depending on the focal length of lens and exposure times the stars are motion blurred, as they are rotating around the north pole causing the stars being elliptically shaped. The prolongation is larger with increasing distance from the pole and is largest on the celestial equator. The major axis of the ellipse is tangential to the direction of rotation, the minor axis of the ellipse points to the centre of the rotation (see Figure 1). The intersection of all lines specified by minor axis is the centre of rotation we are looking for. In order to find it the Hough transformation can be used (Chen et al., 2010). This transformation is often used in computer vision, primary for line detection and has been used in astronomy, for example, for meteor detection in Trigo-Rodriguez et al. (2008). Let's have a line defined by point $A_0 = [x_0, y_0]$ and with direction angle φ. In Hough space the same line is defined using θ and r

$$r = x \cos\theta + y \sin\theta \tag{1}$$

where $\theta = -\frac{\pi}{2} + \varphi$ is the angle between the x-axis and the line connecting the origin with that closest point and r is the distance between the origin and the closest point (see Figure 2). A point in x-y space is defined as a sine function $r(\vartheta)$ in Hough space, while a line in x-y space is defined as a single point in Hough space. Usually, the usage of Hough transformation is to open binarized image which include lines, where it transform every point of lines into the Hough space. In our case, we do not need to make binary image with all the lines created in direction of minor axis from selected stars. Because we know parameters A_0 and φ of all these lines (star location and direction of its minor axis), we can

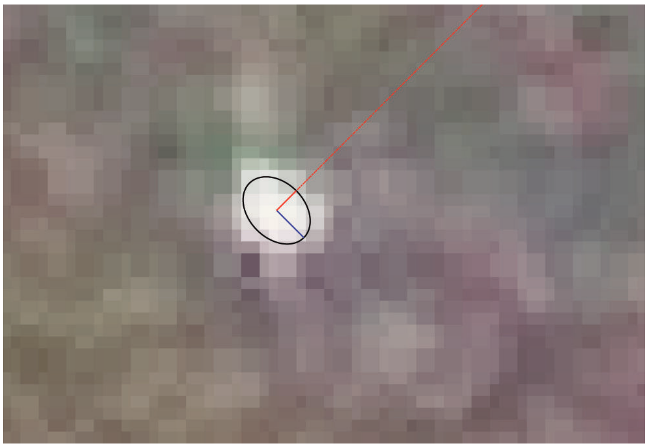

Figure 1. An example of selected star. The major axis is blue, the minor axis is red. The red doted line points toward the centre of rotation of the image.

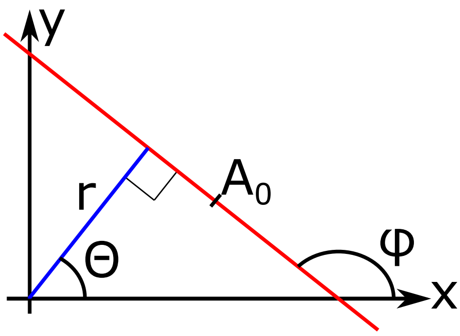

Figure 2. Point $A_0[x_0, y_0]$ and direction angle φ define the red line. In Hough space, the red line is defined via the θ angle and the distance r from $[0, 0]$ to the line.

calculate r and θ parameters and put them directly into Hough space. Notice that if the lines have intersection point in xy space, then it is sine function that is going trough points of those lines in Hough space. In real case we must fit sine function to obtain coordinates of intersection point aka north or south pole Figure 3. We use standard fitting model

$$r = a \sin(b \cdot \theta + c) \tag{2}$$

$$r = a \sin(c) \cos(b \cdot \theta) + a \cos(c) \sin(b \cdot \theta) \tag{3}$$

From witch we can obtain coordinates of the corresponding point

$$x_0 = a \cdot \sin(c), y_0 = a \cdot \cos(c) \tag{4}$$

In this paper, we select 100 stars from the image depending on their brightness,

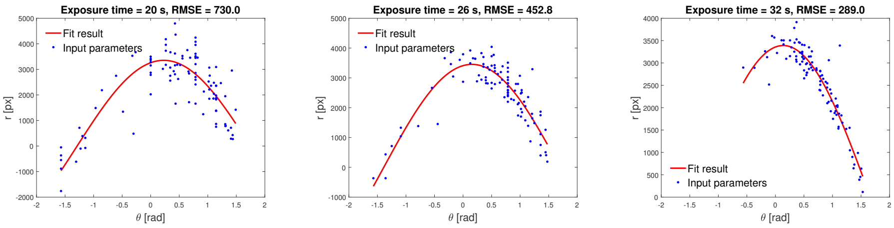

Figure 3. Fit of intersection point in Hough space from input line parameters for different time of exposure (from left 20s, 26s and 32s).

size, shape and location. The algorithm can not work with circular stars, so we select stars according to the eccentricity of their shape. All required parameters are calculated from binarized preprocessed image.

For every exposition the position of centre of rotation is calculated and is compared with real rotation point, Euclidean distance of points is calculated. Figure 4 shows positions of all calculated points and the original. Positions are also provided in 1 where is also calculated RMSE of all fitted functions.

Table 1. Positions of calculated centre of rotation, distance d from real centre and RMSE of the fit.

Exposure time [s]	$x_0[px]$	$y_0[px]$	$d[px]$	RMSE [-]
Original	3255	414	-	-
20	3259.6	785.3	371.3	730.0
26	3410.4	539.8	199.9	452.8
32	3357.1	471.8	117.3	289.0

As a complementary source of information, the eccentricity of the stars can be plotted as a function of its position. As Figure 5 shows, this obvious method also gives some information about the location of the pole, but as figures minimum are being extrapolated (Lowess) from data, estimating the pole position outside of the image would be very problematic.

4. Conclusion

Paper shows that our proposed algorithm to search the pole using properties of Hough transformation has potential to locate the pole. As expected, precision increases with longer exposure times. Stars with bigger eccentricity give better

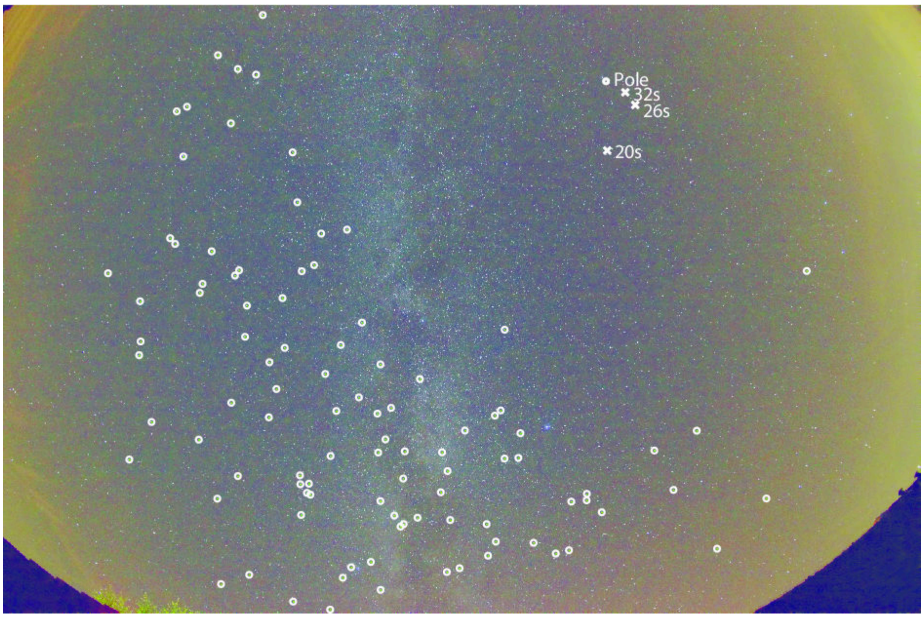

Figure 4. Enhanced image of the sky. Marked stars are selected by the algorithm. The position of the pole and calculated rotational centres for all exposures are showed.

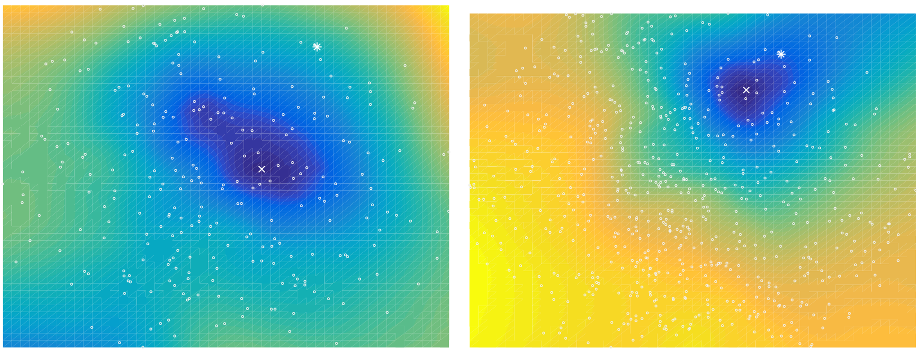

Figure 5. Fit of location of the pole from the eccentricity of the stars. The cross is the position of estimated location of the pole while star is its original position. Left image is for exposure time 20 s, right image is for 32 s.

information about the direction of rotation because they are scattered over more pixels. Difference between 20 and 32 seconds is about 60% but in RMSE it is 259% and distance is 316% improvement in precision. But in most times system uses as short exposure as possible, therefore worst case scenario is the most common. As the first hint for blind astrometric solution algorithm can give limited information but precision in hundreds of pixels is still too high. It is clear that algorithm should be enhanced, we plan to use better algorithm for calculating the centroid, and orientation of the ellipse approximation of the star using weighted calculation from the intensity in the star pixels and not only by binary mask created by simple thresholding. For this reasons, we consider this algorithm only as a proof of concept. Algorithm is usable for all weather monitors as well as more sophisticated devices like described by Castro-Tirado et al. (2008).

5. Acknowledgements

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References

Castro-Tirado, A. J., Jelínek, M., Vítek, S., et al. 2008, in Proceedings of the SPIE, Vol. 7019, Advanced Software and Control for Astronomy II, 70191V

Chen, L., Wang, L., & Xiong, J. 2010, in Proceedings of the 2010 International Conference on e-Education, e-Business, e-Management and e-Learning, IC4E '10 (Washington, DC, USA: IEEE Computer Society), 350–353

Janout, P., Páta, P., Bednář, J., et al. 2015, in Proceedings of the SPIE, Vol. 9450, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, 94501I

Trigo-Rodriguez, J. M., Madiedo, J. M., Gural, P. S., et al. 2008, *Earth Moon and Planets*, **102**, 231