OBSERVING FAINT BINARIES WITH GAIA

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ABSTRACT

The possibility to combine the information from all the transits to produce one combined image is studied. The aim of the study is to find the absolute limits for the detection of the secondary stars that could be detected in the close vicinity of the primary star. Patches from the simulated AF11 data are used in the simulations and the possible method that could be used to detect the faint companions is presented. It is shown that in the ideal case the secondary with $G \approx 24$ mag or $\Delta m \approx 8$ mag could still be found from the combined image. Signal-to-noise ratio curves are given to evaluate the secondary detection.

Key words: Gaia; Image processing; Visual binaries.

1. THE METHOD

The window combining method used in the simulations is a simple but fast mapping procedure in which elongated Gaia pixels or one dimensional data in the patches is subsampled to the output grid that have smaller square pixels than in the initial image. Hence, the technique resembles the drizzling technique developed by Fruchter & Hook (2002). The details of the method and the full description of the simulations can be found in Nurmi (2004).

Initially a 2-D window at an epoch t is obtained around the selected star at the satellite in the astrometric field of view (AF11). Due to the data transfer limitations only part of the initial pixel data in the CCD is transmitted to ground.

The window combination is started by stretching the patches to correspond to the initial size of the 2-D windows. Secondly, the centre of the window is shifted and rotated by the angle that is known from the scanning law. After these steps the absolute positions of the windows, or alternatively the centroids of the primaries, overlap perfectly.

After these initial steps the windows are mapped to the output grid to produce the new image. The kernel of the algorithm (Fruchter & Hook 2002), that is repeated until all the patches are combined, is

$$W_{xy}^{k+1} = a_{xy,x_c y_c} w_{x_c y_c} + W_{xy}^{k} \tag{1}$$

$$C_{xy}^{k+1} = \frac{a_{xy,x_c y_c} i_{x_c y_c} w_{x_c y_c} s^2 + C_{xy} W_{xy}^{k}}{W_{xy}^{k+1}}, \tag{2}$$

where C_{xy}^{k} is the combined intensity at k_{th} iteration in the final image, W_{xy}^{k} is the combined weight and $w_{x_c y_c}$ is the individual weight of the pixel, $a_{xy,x_c y_c}$ is the geometrical weight factor (overlapping fraction), s is the fraction between the size of the output pixel to the input pixel ($s = 1/3$ for Gaia) and finally $i_{x_c y_c}$ is the measured pixel value at (x_c, y_c). If needed, different weights $w_{x_c y_c}$ can be introduced to individual pixels so that the geometrical distortions or any relevant corrections can be taken into account. In the equations x and y refer to pixel positions in the new image. Whenever a_{xy} is calculated the elongated shape of the pixels and partial overlaps between the initial pixels and the underlying C_{xy} image frame are taken into account.

To calculate the signal-to-noise (SNR) values of the secondary sources in different parts of the combined image, we have to consider the noise variations in the final image. In the calculations the Poisson noise, the readout noise, the noise due to the background and the dark current are taken into account. The photon noise from the secondary star is ignored, since we have assumed that it's contribution is much smaller than that of the primary. Therefore, these calculations are limited only to faint secondary sources. Due to the correlation of noise in adjacent pixels SNR is calculated as the average value from only 4 pixels centred to the secondary position. The signal value corresponds the peak-to-background level value measured at the maximum.

2. SIMULATIONS

The method was tested using the simulated AF11 data from the Gaia Instrument and Basic Image Simulator, GIBIS (version 1.4, Babusiaux et al. 2001). We assumed that the transit angles are randomly distributed and the stars are not moving in the image between different transits. The expected position and magnitude errors are included in the simulations. To study the surroundings of the primary star the expected Line Spread Function (LSF) is subtracted directly from the transit data and only the subtracted patches are combined. To do this properly the magnitude and the spectral type of the primary star must be known before the analysis to obtain the proper LSF. One example of the combined image is shown in Figure 1. The noise in the image is high close to the centre of the image and at the edges. The noise is high at the centre due to the Poisson noise from the primary and it is also high close to the edges of the image, since the overlapping of the pixels is only partial outside the central region and the increase in SNR is not so good. For AF11 windows the pixel scale used in the combined image is 44.2 mas.

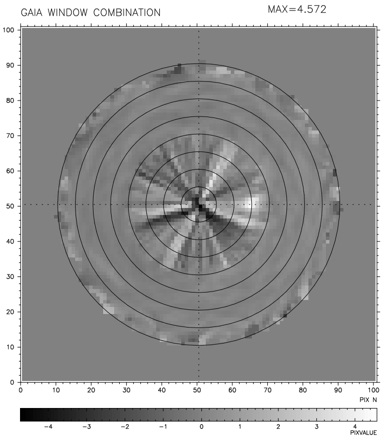

Figure 1. The combined image of a binary system from which the primary contribution is subtracted is shown. The system consists of the primary $G = 14$ mag and the secondary $G = 22$ mag. Random Gaia scan angles (80 transits) are used during the combination. The secondary star is easily detected at the position 15 pixels away from the primary.

To evaluate the expected detection levels in the ideal case, several simulations were run for binaries having different separations and magnitudes. The colour $B - V = 0$ is the same for both components, hence the Gaia magnitude $G \approx V$. In the left panel of Figure 2 the SNR curves are shown for the 14th magnitude primary and $G = 22$ mag secondary. In the right panel the primary has $G = 18$ mag and for the secondary $\Delta m = 6$ mag. These two figures show the main results of the simulations. In the images containing the bright primary, the SNR increases gradually as the secondary position moves away from the primary position, since the Poisson noise diminishes. However, the noise increases again close to the edge due to the partial overlapping of the pixels and the SNR curve changes. For the faint primaries ($G > 18$ mag) the Poisson noise is limited to a small region in the centre of the image and the magnitude gain outside the central region is better than that of the bright stars. Hence, there is a maximum in SNR between 10 and 17 pixels. A more complete description of the simulations can be found in Nurmi (2004).

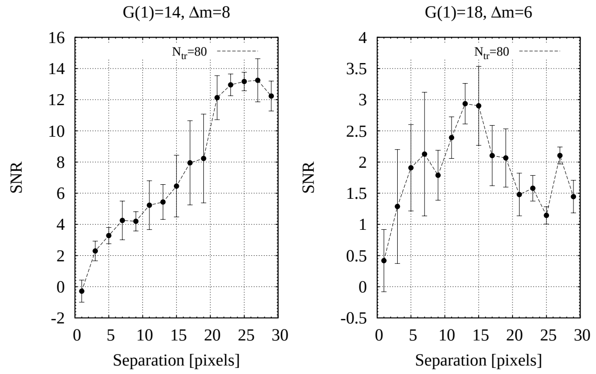

Figure 2. Calculated SNR curves of secondary sources as a function of angular separation from the main source for two different binary magnitudes. The SNR curves are for the systems with 80 combined images.

3. CONCLUSION

Based on the performed simulations we conclude that it is possible to detect stars ($SNR \approx 3$) close to the primary down to $G \approx 24$ mag or $\Delta m \approx 8$ mag in the ideal case and in the best possible position if the AF11 data from all the transits is combined after the mission.

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