Optimization of a motion tracking and mapping method based on images of the solar corona

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Abstract. The study presents the current stage of development and application of a motion tracking and mapping method, based on solar corona images. The object of discussion is the problem of image processing during the extraction of features of interest in the sequence of solar prominences images. At first the method requires calculating techniques that ensure processing time-period commensurable with the time-period of the fastest developing part of the prominence body. That defines the necessity of optimization of the basic algorithms. The paper describes results of test procedures on accepted approaches for reducing the operation time by parallel processing of the images. The method also requires presentation of the lightness information independently of the sensor of particular coronagraph and image file format. This investigation proposes two techniques for achievement the identity of images from different instruments/sensors.
Key words: image processing; solar images; parralel programming; image exchange

Introduction

The method for motion tracking and mapping, based on solar corona images (Pavlova, Koleva, 2008; Pavlova et al., 2010) proposes an ability for modeling the dynamical changes in solar prominences during its evolution. However, to obtain a correct model for image processing we have to ensure an optimal accuracy and reliability of the extracted features, fixed as 2D compass directions of layers. The test has been conducted on sequences of images that include several elements - an artificial moon visible as a black half circle, the solar corona with bright prominences above the moon and near them - background of a shining Earth atmosphere. A correction for Earth rotation was also applied, using some static elements in the images as a reference.

Since the object of interest are only the moving prominences' parts, the background shining was removed before the main process of the compass directions extraction. The method supposes a usage of calculating techniques that ensure at first - an optimal time-period for image sequences processing commensurable with the time period of the fastest developing parts of the prominence (several minutes), and second - a presentation of the lightness information independent from the sensor of particular coronagraph and image file format.

For this purpose all the processing is executed by specially developed software. We used images from two different instruments - Small Coronagraph (130/3450 mm) at the Astronomical Institute of Wroclaw University, Poland and 15-cm Lio-coronagraph mounted at NAO Rozhen. The sequences were registered with H_α filter. All filtegrams from Wroclaw coronagraph were degitized with the automatic Joyce-Loebl microdensitometer at National Astronomical Observatory Rozhen, Bulgaria to fits format files. The images from NAO were obtained with digital camera Canon EOS 305D ($8Mpxs$) in jpg file format.

The paper presents results from analysis of testing the method on different sequences of images and suggests possible decision of the mentioned problems.

1 Problems and decisions

At this stage of our work the implemented algorithm includes several steps. Block scheme of the algorithm is represented at Fig. 1. All operations over input images sequence can be separated into two steps. At the first step we perform pre-processing: algorithm estimates photo-spherical shining and removes it. A Gauss filtration and image sharpening were also applied. At the second step method calculates image gradients and performs a map of motions.

The described method was implemented in C programming language. Initially the results obtained from serial implementation of the algorithm with a number of input images with different sizes and levels of noise were verified. After a successful verification of the algorithm the possibilities for its parallel execution were discussed. The main objective of the parallel implementation of the algorithm is detection of hot-spots (i.e. places where the application is spending a lot of time) and its elimination, especially at the stage of "tracking and mapping a motion". This will provide us with parallel version of the algorithm suitable for implementation with GPGPU technology (CUDA, OpenCL). For this purpose an OpenMP API and tools for applications profiling have been used.

In Fig. 2 the estimation of the possibility of parallel performance of the implemented algorithm is shown. We used computer architecture with 4 core processor and input images with sizes $3400 \times 2300px$ and $1700 \times 1100px$.

As you can see from the chart, using of OpenMP, we achieved relatively good execution times on the selected computer architecture. Execution time of the method is reduced by increasing the number of threads that execute operations on pixels. Improvement in the execution time is not strictly linearly due to the available dependencies in code (data dependencies, order of the operations, etc.) which cannot be removed.

The tests on different sequences outline the following problem: The mark of the images used for displacement compensation is visible with low contrast (Fig. 3). It means that the coincidence of the objects depends on subjective decision for pixels' correspondence.

Background shining elimination by calculating threshold from statistical estimation of the upper three and lower three rows and left three and right three columns didn't eliminate pixels around the prominence (Fig. 4).This effect was minimized at the stage of elimination of turbulence and extraction of directions.

The received optical signal is monochromatic in red color since the H_α filtering limits the radiation to wavelength 656.3 nm that is inside the visible range of optical radiation. Depending on the type of the sensor the color of this radiation could be directly reproduced or additionally applied to the images. The first leads to digital presentation of the picture with three matrix for R, G and B reproducing signals with a fixed relations between them; the second - presentation with one pixel's matrix and corresponding palette for coloring. From the point of view of image processing in first case the images

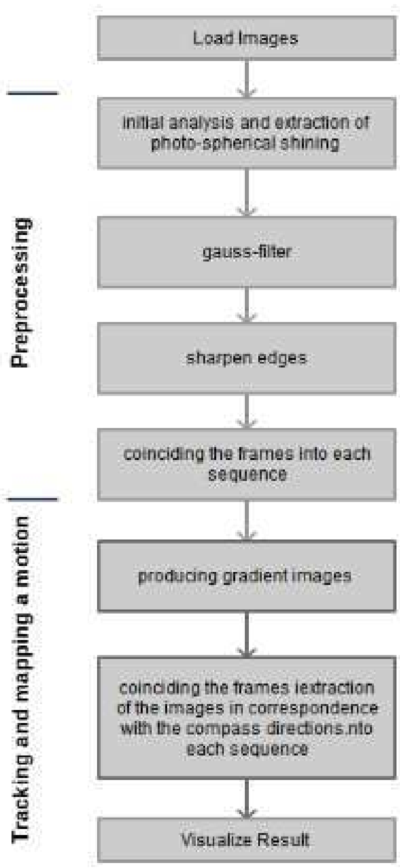

Fig. 1. Blok-scheme of the implemented algorithm

are classified as colored, in the other - the images are monochromatic. The images obtained in fits file format are monochromatic, and the jpeg files are colored. Nevertheless, the processing of both types of images for one prominence, have to produce identical results. That is why there has to be a relation between presentations of the pixel's information in the both cases. Colorimetrical transformations between different forms of appearance of the H_α color give a criterion for needed identity. In accordance with standards in colorimetry (CIE, Colorimetry, 1996; ICC.1.2004-10, 2006, Image technol-

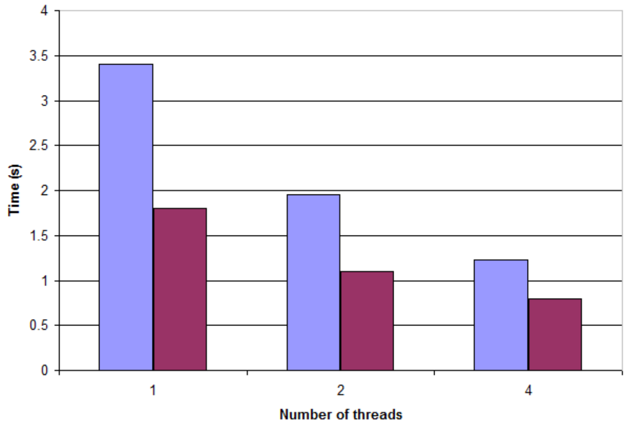

Fig. 2. Time results from algorithm execution

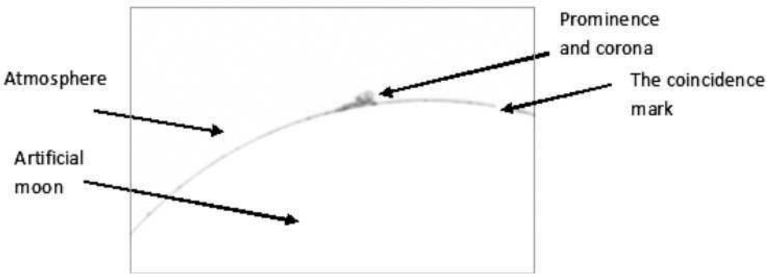

Fig. 3. Common description of the image

Fig. 4. Cropped images of prominence before **(a)** and after **(b)** background shining removing and after extraction of directions and coloring by hue **(c)**

ogy colour management - Architecture, profile format, and data structure), the spectral colors should be presented with maximal saturation independently of the sensor. By currently used calibration standard the camera transforms spectral colors to space of sRGB triangle (ICC.1.2004-10, 2006, Image technology colour management - Architecture, profile format, and data structure). Maximal saturation occurs when one of the reproducing signals R, G or B is equal to 0. The coordinates of the position of the color chromaticity corresponding to H_α could be fixed as a point at the border of the figure. The relation has a simple graphic presentation in basic chromaticity diagram (CIEXYZ -Locus) and is given in Fig. 5. Also the Table 1 includes the coordinates of the base points of the reproducing signals for sRGB triangle in the CIEXYZ chromaticity space and the coordinates of the H_α color result from simple calculation of the cross point position.

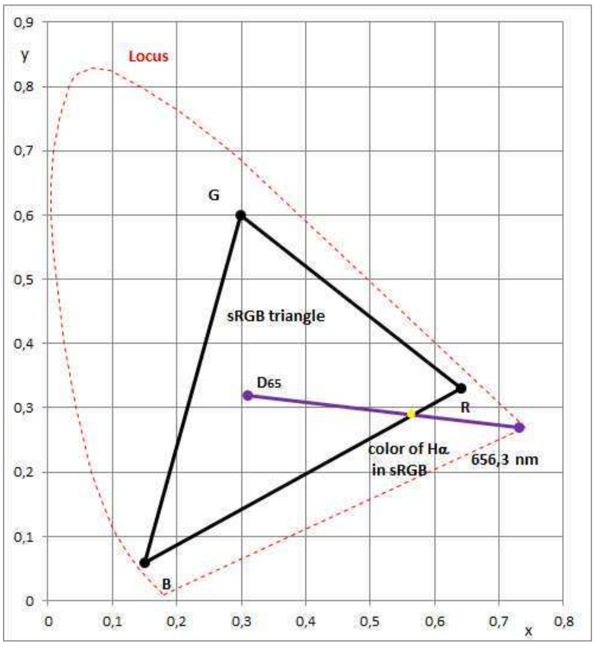

Fig. 5. Color position of H_α in sRGB chromaticity triangle

Monochromatic images in fits format do not need testing for RGB ratio in contrast to the color images in jpeg format. According to transformation between input optical signal and color image (ICC.1.2004-10, 2006, Image technology colour management - Architecture, profile format, and data structure), the radiation after H_α filter has to produce a ratio between RGB components 1:0:0,184 (without green component). The mentioned ratio could be used as a criterion for identity of the images from different instruments and sensors. Fig. 6 shows the significant part of the image obtained from Lio-coronagraph and the histogram for the reproducing RGB channels. The histograms' distributions show appearance of all components

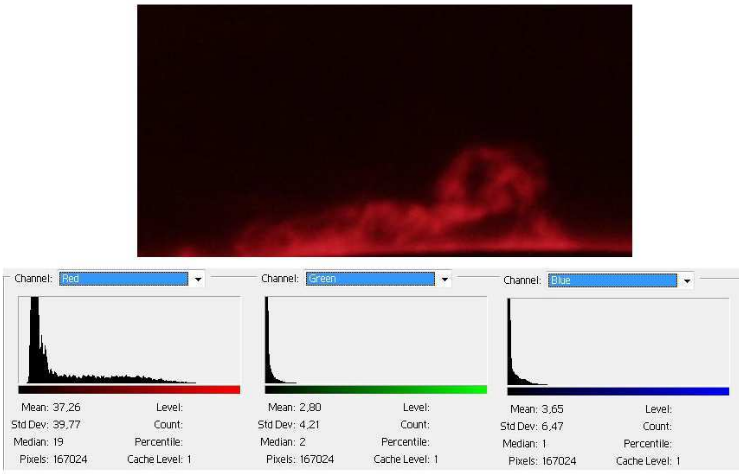

Fig. 6. Histograms of RGB channels of color image

and suppose appearance of green reproducing signal and subsequent increasing spatial noise.

We suggest two approaches to compensate the difference between monochromatic and color images obtained from different instruments. First one supposes additional image processing over saturation and hue of the pixels. The second one needs an initial calibration of the camera to reproduce color of the pixels as ratio of the RGB signals equals the calculated for the H_α.

Figure 7 shows the results of maximal saturating of the image, and applied rotation of the hue scale since the ratio between average values for R and B becomes equal to 1:0,18 (hue=349 degrees).

2 Conclusion

The described tests offer three suggestions:

1. A technique for parallel programming.

Implementation of methods and algorithms for image processing is a complex task which targets require final result and also must provide desired performance for the final solution on different computer platforms. We used OpenMP API, which is a good way to estimate possibility for increasing performance of the method by using parallel programming. Described method has great potential for parallel execution and one of the possibilities for improvement of its performance is using of massively parallel processing (GPGPU or heterogeneous architectures) through technologies like NVIDIA CUDA or OpenCL.

2. A technique for background shining elimination;

3. Criterion and technique for achievement of the identity between H_α images from different instruments/sensors.

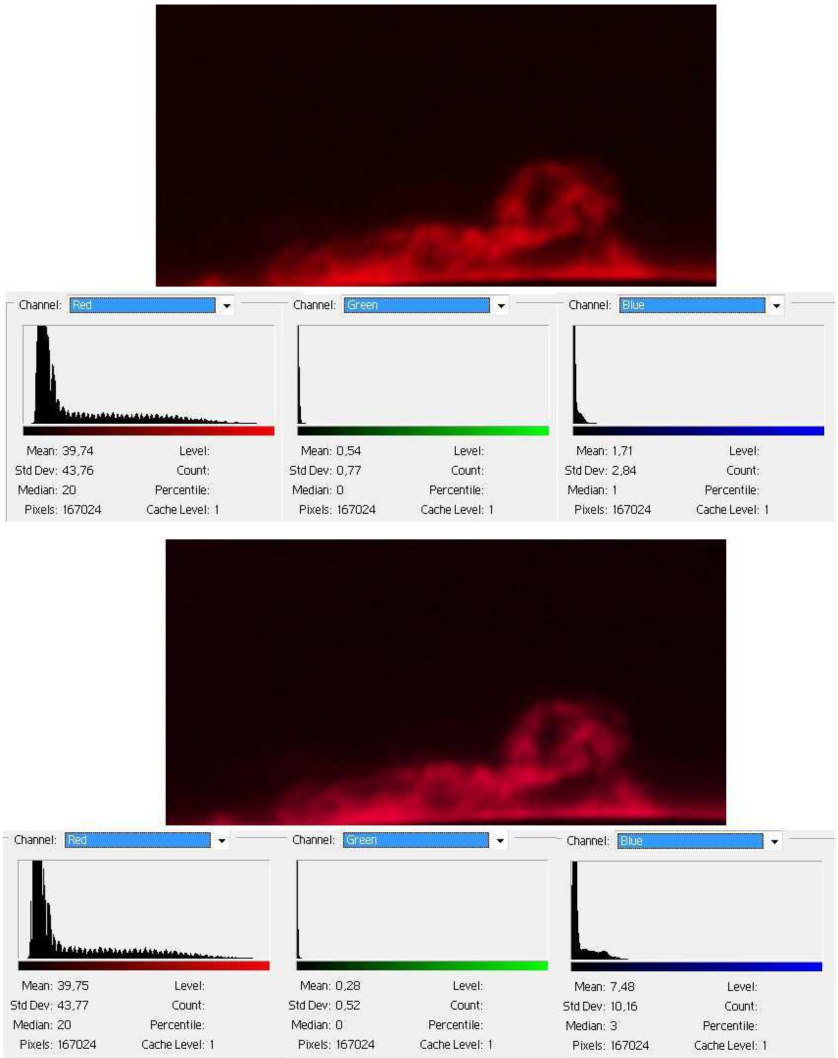

Fig. 7. Image and RGB histograms after maximal saturating **(top)**, and maximal saturating and 10 degrees hue rotation **(bottom)**

The object of future work is development and testing a calibrating technique for registration color images with real for H_α color. Another object of future testing is the limit of the level of compression of the file format suitable for obtaining significant results.

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