Mapping low coronal flow trends via time dependent AIA image processing

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ABSTRACT

Applying the Time-Normalized Optical Flow (TNOF) image processing technique to AIA extreme ultraviolet (177-305 nm) data reveals fine-scale and faint plasma motion that are tracked through optical flow methods, giving 2-D flow maps. The flows detected thus far appears to be oriented in the low corona [1,2], but the Lucas-Enaptured (L2) method has known weaknesses near the solar limb, due to small separation in observational position, and varies in quality across AIA cameras. To reliably refine the method, synthetic image data is developed with a well defined velocity field and will serve as the testing platform to separate systematic biases from true flows. Once fully vetted, the strength of the project lies in understanding the faint moving disturbances that propagate and persist during the "quiet sun" period that is the standard solar condition. The method may be adapted to include elevation flow trends in/out of the low corona should tandem spacecraft be flown at L1 & L5, allowing 3-D maps of flows.

TIME NORMALIZED OPTICAL FLOW

Continuous AIA data is well suited for dynamics by normalizing a sliding time window on consecutive observations [2]:

\[ \frac{\Delta S(x, y)}{\Delta t} = \frac{S(x_2, y_2) - S(x_1, y_1)}{t_2 - t_1} \]

While time normalization limits still image structural context, it is crucial to reveal temporal faint motions across the solar disk that are usually dominated by spatial variations in intensity. In prior studies, application of TNOF has been most effective for AIA 171/193 images, with less coherent detail in other channels.

OPTICAL FLOW TRACKING

The LK method for optical flow analyses successive images of the same scene and draws an estimated path that features move along [3]. It does so by identifying changes in a pixel’s intensity and comparing it against the known intensity gradients in the region of the pixel:

\[ \frac{\Delta \text{Intensity}}{\Delta x} \]

Presently, optical velocity paths drawn via this method have aligned well with visible structures in MGN contrast enhanced images, there remains many paths with no clear contextual alignment across the "Quiet Sun".

SYNTHETIC DATA

Success with TNOF and LK methodology appears promising and has discovered ubiquitous and continuous propagating disturbances across the solar disk [2]. And yet, discrepancies in optical velocities among different AIA channels may be due to systematic scaling biases attributed to user-adjusted spatial and time-smoothing parameters. Without independent verification, synthetic data provides the best alternative for a controlled test environment.

The resulting 2-D velocity field is created and may be manipulated globally or with discrete discrepancies. For display purposes, the N=10 field is unadjusted:

Flow within this field is mapped in two distinct methods, the first is via line-integral convolution (LIC) [4]. Linear and curvilinear filtering is performed locally along streamlines defined by the vector field to approximate flow speed magnitude. The algorithm is computationally expensive & reversible, but yields precise results for any particle motion within the field:

The second method is via direct interpolation of the vector field. This yields reversible time-series positions for an arbitrary number of particles. Each particle is set to a high intensity brightness and diffuses as it moves, complicating the original field in a verifiable manner:

As shown in Fig 10, TNOF is a powerful tool for isolating faint, small-scale moving disturbances across the time series of 2-D images.

FUTURE WORK

The testing platform will evolve further to:

- Add solar-like features & resolution similar to AIA
- Implement & refine LK method on all channels
- Compare LK/LIC quality against other techniques
- Optimize efficiency well enough to map small-scale, faint motion across the entire AIA dataset.

REFERENCES


See inserts on next page

Scan the QR code below to see a one minute video of Figures 1, 3, 5, 10
Or enter the URL: http://users.aber.ac.uk/gam27/RAS2019animation.mp4

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Presented as a difference in movies, the LK method, as direct interpolation of non-diacritical fiducial points, matches well with synthetic observations. This new method is similar to the elements of the LK method, but as it is an interpolation process rather than a smoothing technique, it is not as biased as LK method.

The TNOF method is a powerful tool for isolating faint, small-scale moving disturbances across the time series of 2-D images.
Synthetic data is created by applying a sinusoidal basis function that randomly determines the underlying 2-D velocity field [2]:

\[ S(x, y) = C + \sum_{k_x=1}^{N} \sum_{k_y=1}^{N} h_{k_x,k_y} S_{k_x,k_y} \]

Where:

- \( C \) is a constant,
- \( h_{k_x,k_y} \) are random scalars \([-1, 1]\),
- \( S_{k_x,k_y} \) is a constant,
- \( c_{k_x,k_y} \) are random integers \([-1, 1]\),
- \( k_x, k_y \) specify the function order as an \( N \) size box,
- \( i, j = 0, 1, 2, \ldots, n_x - 1 \),
- \( x', y' = \frac{x}{n_x} - \frac{1}{2}, \frac{y}{n_y} - \frac{1}{2}, \ldots \)

The complexity across a single axis of the velocity field is defined by the number of ordered pairs, \( N \), summed within a grid point:

Figure 6: Description of values within the sinusoidal basis function.

\[ S_{k_x,k_y} = \sin(k_x x') \]
\[ S_{k_y} = \sin(k_y y') \]
\[ C_{k_x} = \cos(k_x x') \]
\[ C_{k_y} = \cos(k_y y') \]