Calculating solar differential rotation by automatic tracking of CBPs

Using Hybrid PSO-Snake Algorithm

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FCT
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CA3
Soft Computing and Autonomous Agents

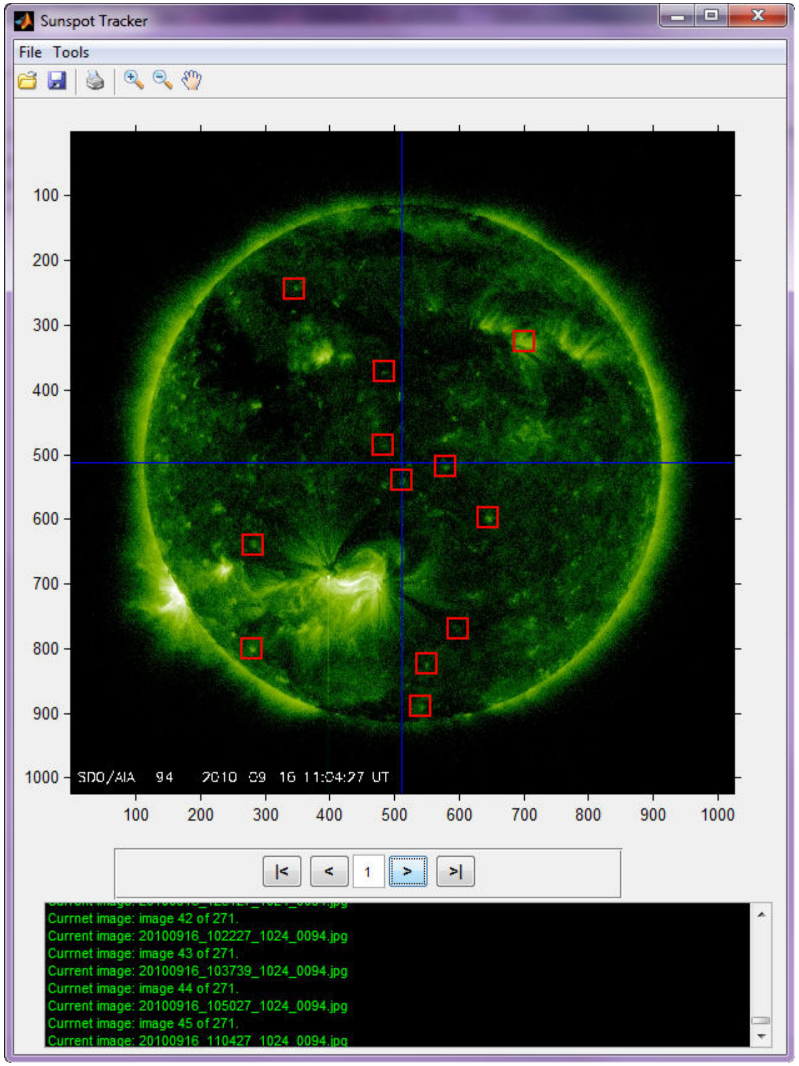
- **Introduction**
  - □ **Disclaimer !**
- **Problem domain**
  - □ **“On rotation of the Solar Corona”, Lorenc. et al. Solar Physics 281.2 (2012)**
  - □ **Sidereal rotational angular velocity of the solar corona**
  - □ **Tracking CBPs**
- **Introduction to Algorithm**
  - □ **Snake Model**
  - □ **Particle Swarm Optimization**
  - □ **Proposed PSO/Snake Hybrid Model**
- **Results**

Rotational speed of the Sun’s surface

- Spectroscopic method
  - By studying the Doppler shift of spectral lines
- Tracer method
  - Tracking precise location of prominent details on the solar disk and determining their speed

Rotational speed of the Sun’s surface

- Tracing Coronal Bright Points (CBPs)



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Currnet image: image 44 of 271.
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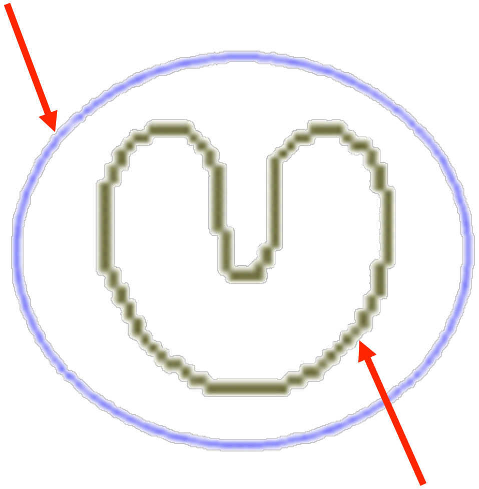
Snake Model

- Initial contour
- Energy
  - Curvature : more energy
  - Stretch : more energy
  - Image features: less energy
- Snake evolves towards image features
  - Edges
  - Boundaries
  - High level information



Initial Contour

Target Contour

Snake Model

- Parametric representation

$$p(s,t) = \left(x(s,t), y(s,t)\right),\ s\epsilon[0,1]$$

- Energy function

$$E_{snake} = \int_0^1 E_{Int}\left(p(s)\right) ds + \int_0^1 E_{Ext}\left(p(s)\right) ds$$

- Internal energy

$$E_{Int} = (\alpha(s)|p_s(s)|^2 + \beta(s)|p_{ss}(s)|^2)/2$$

$$\left|\frac{dp_i}{ds}\right|^2 \cong |p_i - p_{i-1}|^2$$
$$= (x_i - x_{i-1})^2 + (y_i - y_{i-1})^2$$

$$\left|\frac{d^2 p_i}{ds^2}\right|^2 \cong |p_{i-1} - 2p_i + p_{i+1}|^2$$
$$= (x_{i-1} - 2x_i + x_{i+1})^2 + (y_{i-1} - 2y_i + y_{i+1})^2$$

Snake Model

- External energy

$$E_{img} = -I(x,y)$$

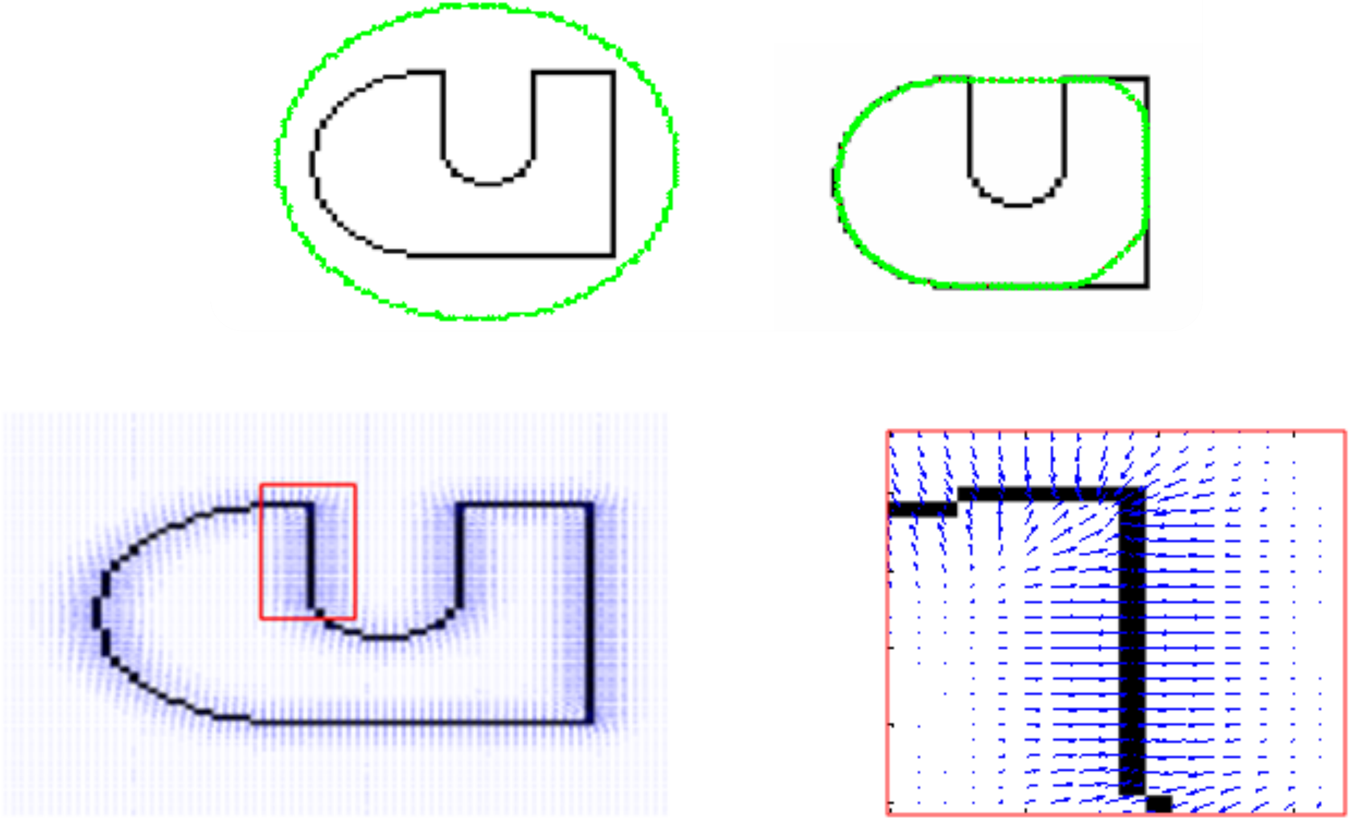
$$E_{img} = -\left|\nabla G_{\sigma} I(x,y)\right|^{2}$$

$$\boldsymbol{\varepsilon}_{img} = \boldsymbol{w} \cdot \left|\nabla^{2} \boldsymbol{I}(\boldsymbol{x},\boldsymbol{y})\right|^{2}$$

- Evolving snake

$$\boxed{\alpha p_{ss}(s) - \beta p_{ssss}(s) - \nabla E_{Ext} = 0}$$

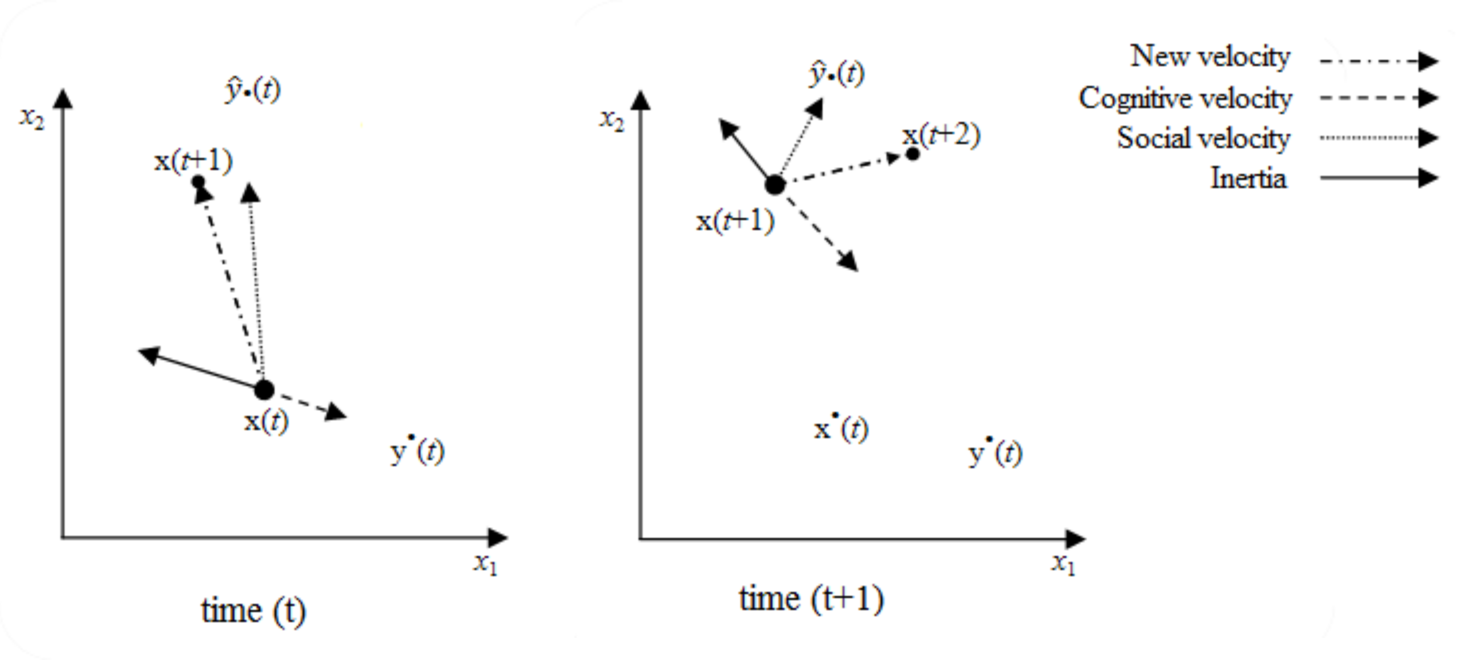
Snake Model – limitations



Particle Swarm Optimization (PSO)

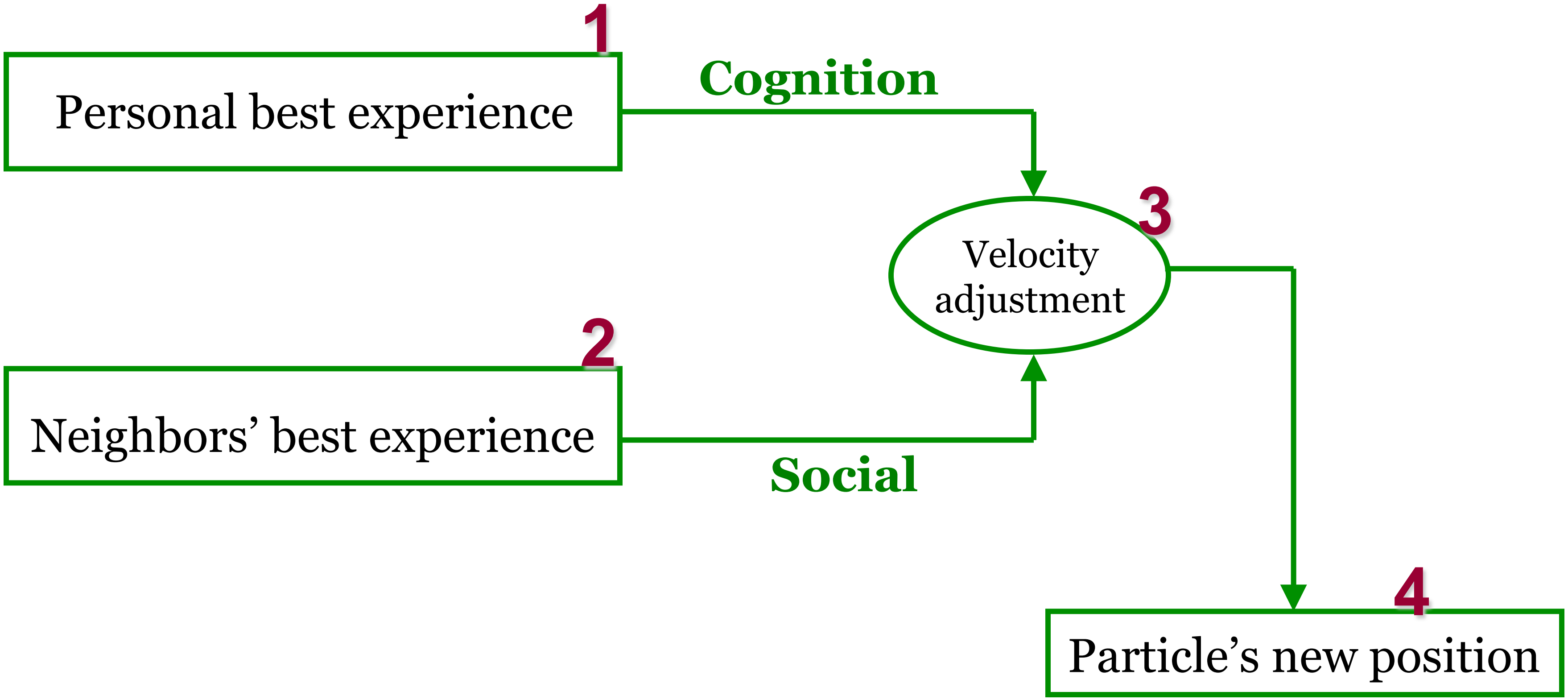
- Inspired from flock of birds
  - Simulating birds search for food
- Adjusting ones behavior according to its neighbors
  - Adjusting velocity
    - One’s best experience
    - Neighbors” best experience

Particle convergence

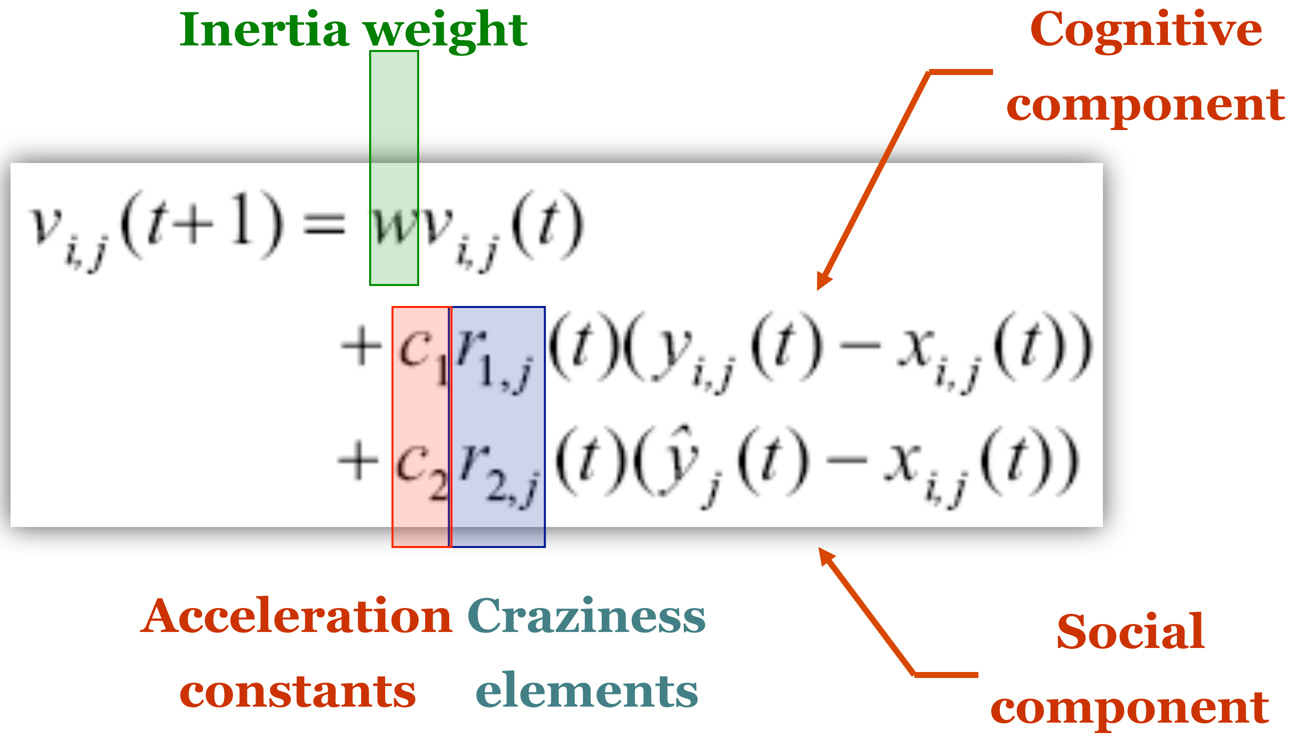


PSO

Updating values



PSO



Inertia weight

Cognitive component

$$
\begin{aligned}
v_{i,j}(t+1) = {} & w v_{i,j}(t) \\
& + c_1 r_{1,j}(t)(y_{i,j}(t) - x_{i,j}(t)) \\
& + c_2 r_{2,j}(t)(\hat{y}_j(t) - x_{i,j}(t))
\end{aligned}
$$

Acceleration constants

Craziness elements

Social component

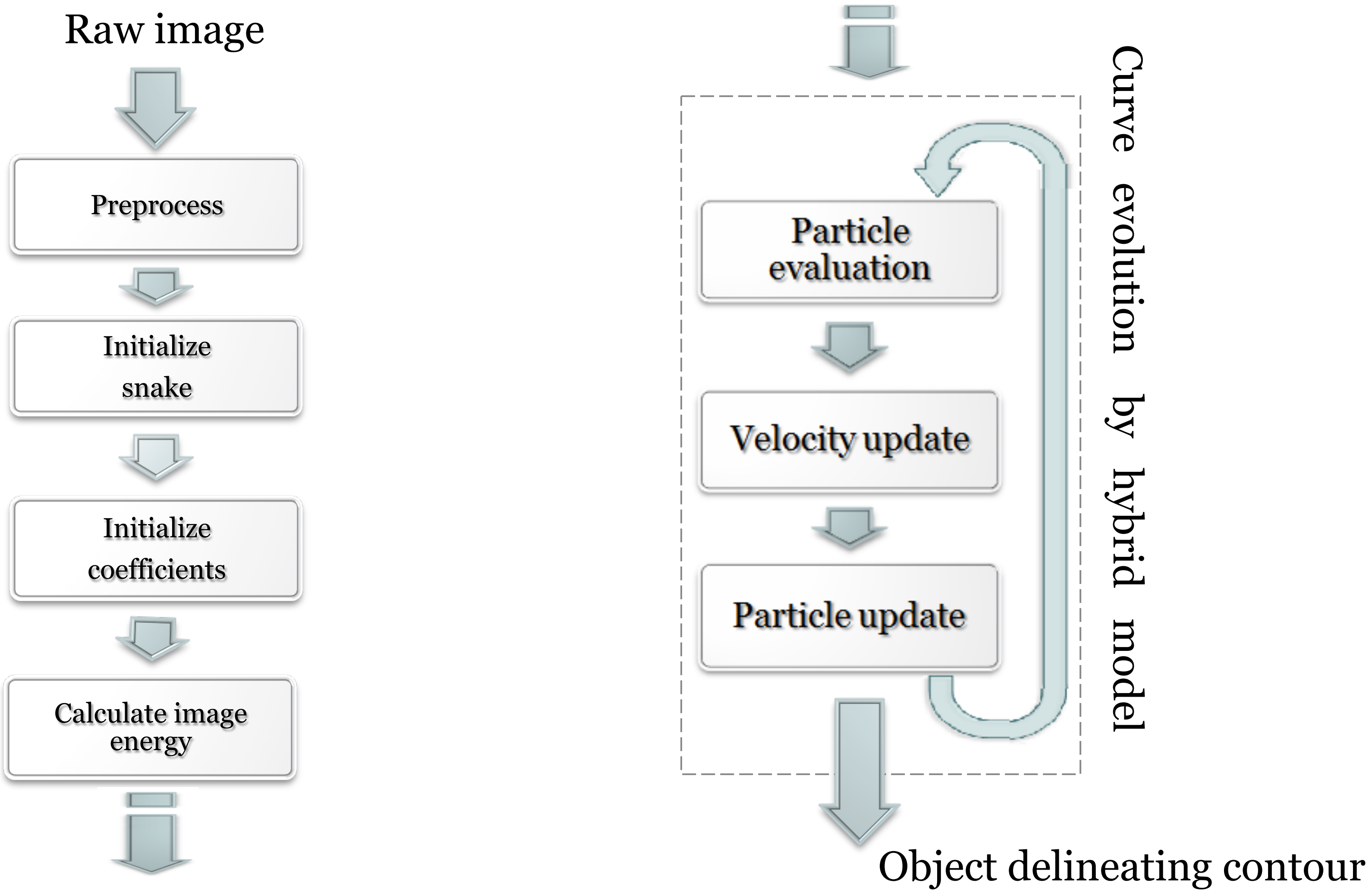
PSO-Snake hybrid

- Fitness evaluation
  - Particle fitness = Sum of internal and external energies

- Particle velocity update
  - Calculating pbest
  - Calculating lbest
  - Calculate snake center

$$v_i(t+1) = \omega v_i(t) + c_1 r_1\left(pbest_i(t) - X_i(t)\right) + c_2 r_2\left(lbest_i(t) - X_i(t)\right)$$
$$+ c_3 r_3\left(\overline{X}(t) - X_i(t)\right) + c_4\left(f.\mathrm{Im}\,age_i\right)$$

PSO-Snake hybrid



Raw image

Preprocess

Initialize snake

Initialize coefficients

Calculate image energy

Particle evaluation

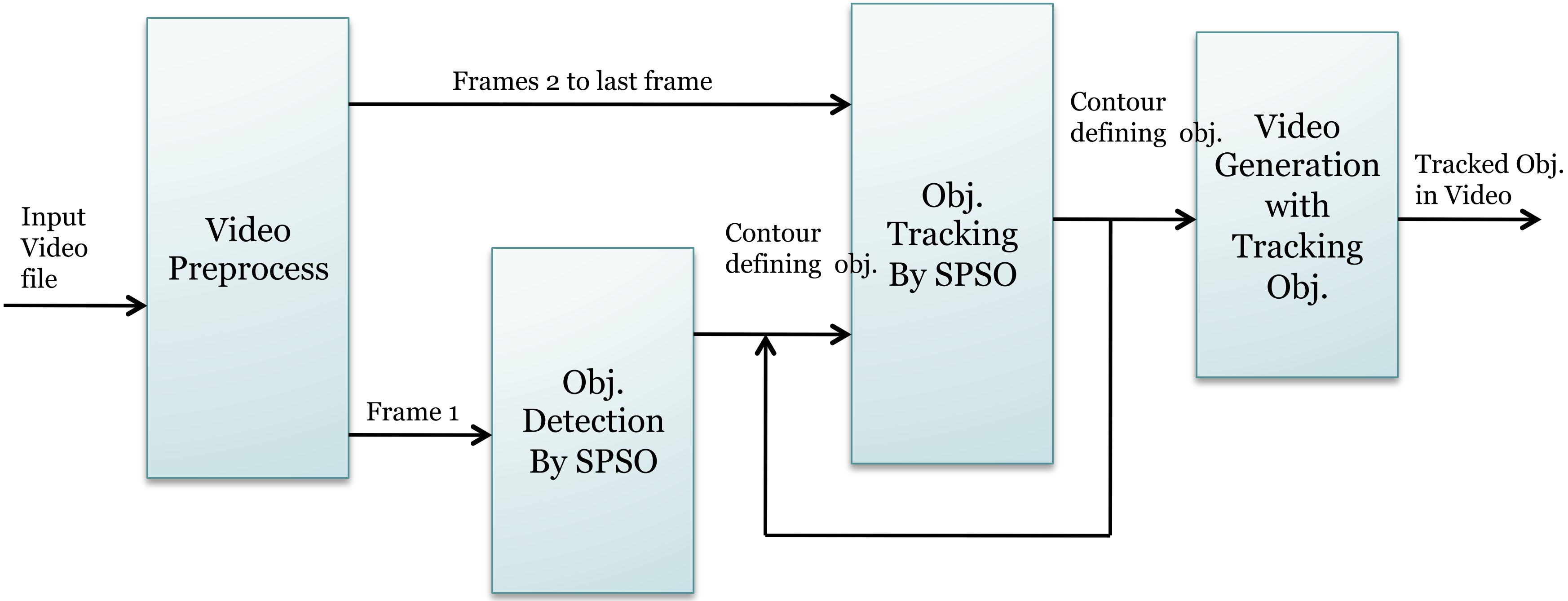
Velocity update

Particle update

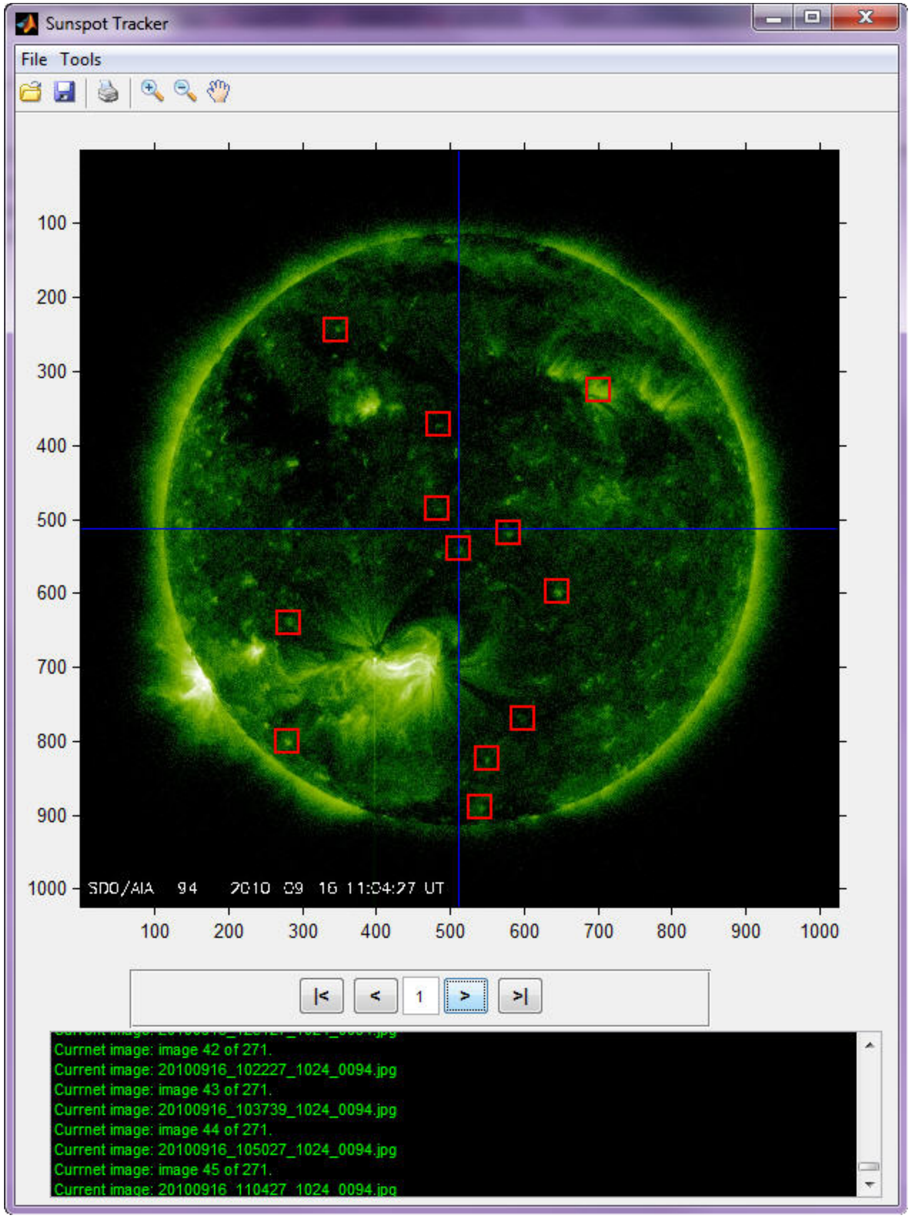
Curve evolution by hybrid model

Object delineating contour

PSO-Snake hybrid



PSO-Snake hybrid in action:



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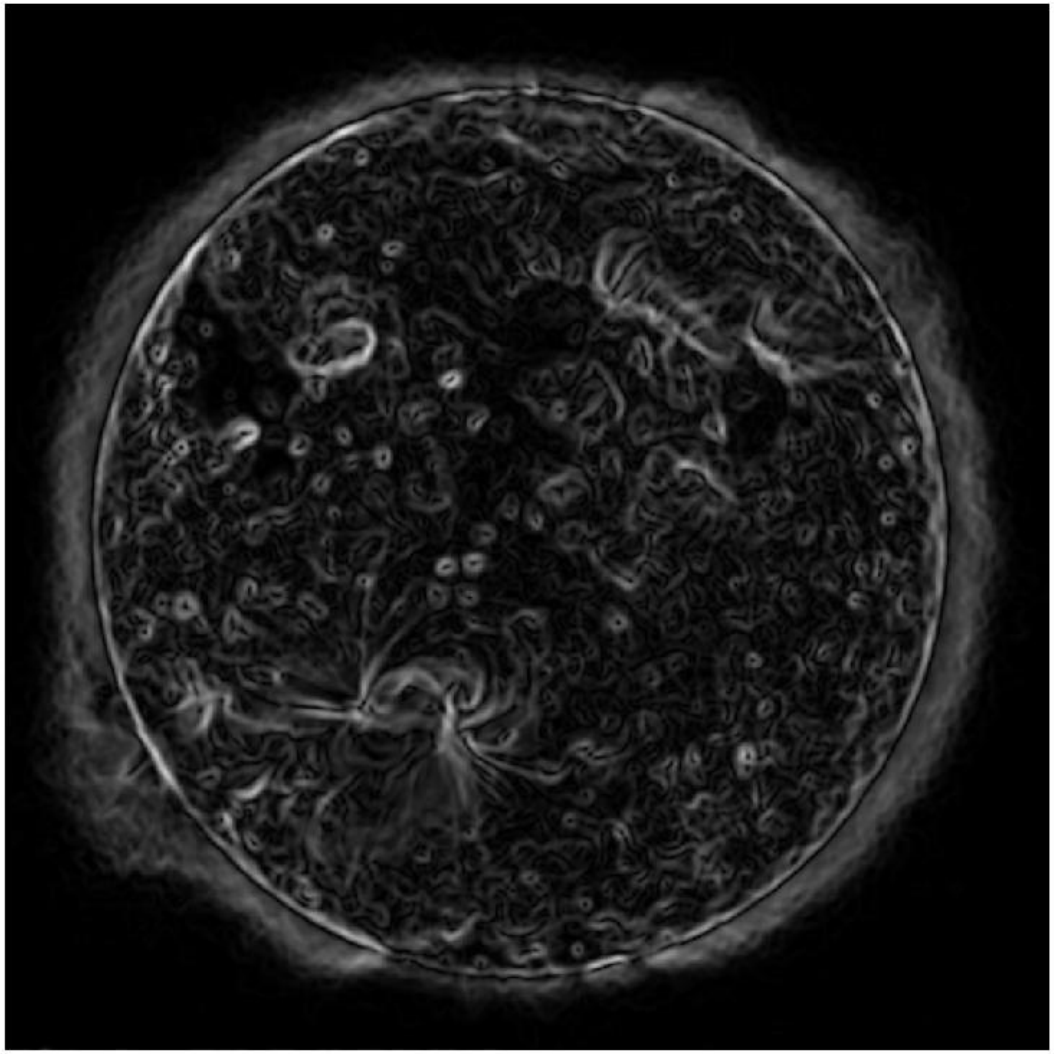
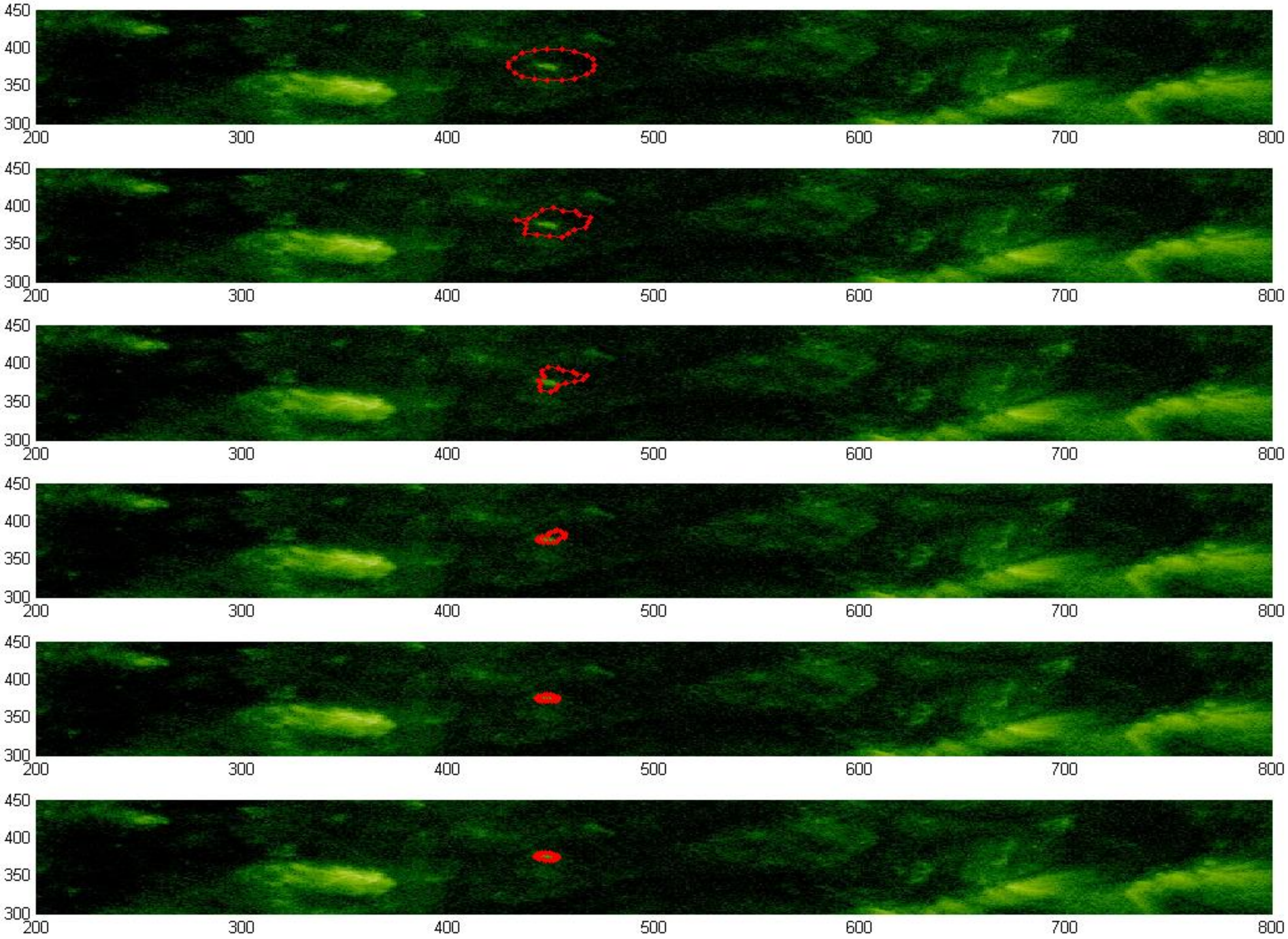
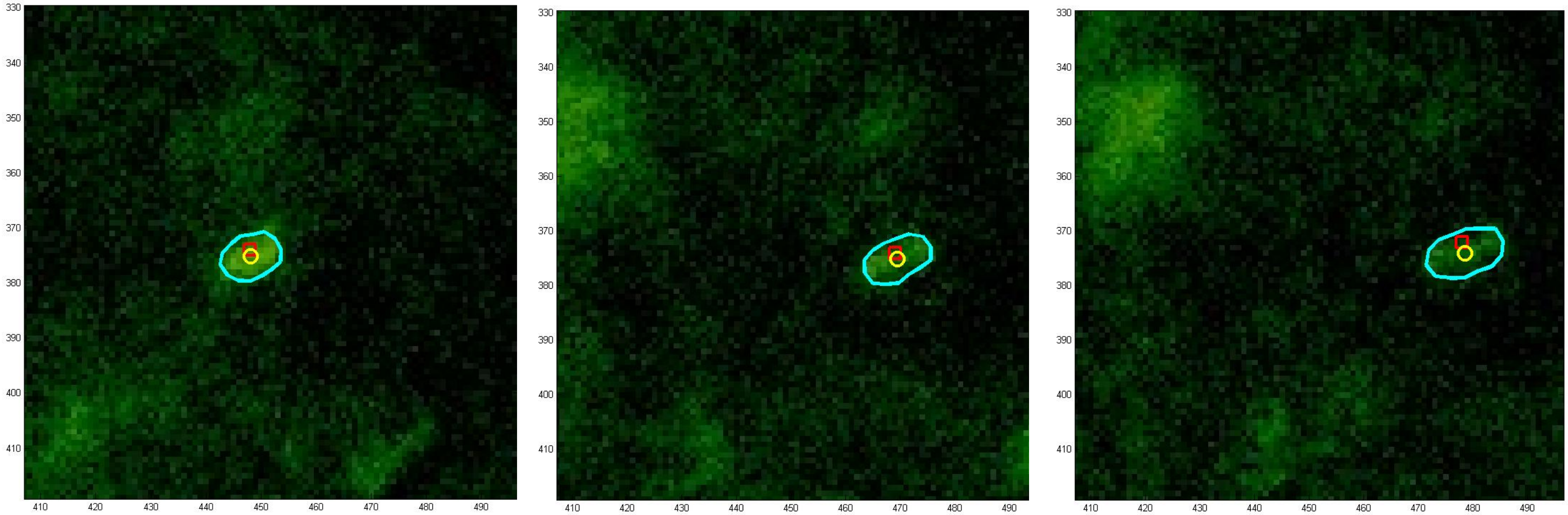
- Image Force



Initial contour: Detection at t_0



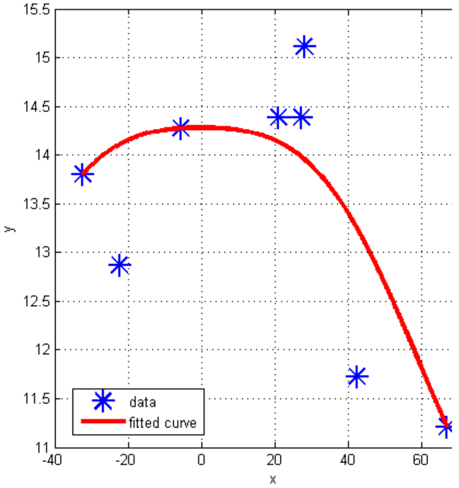
Tracking contour in successive images

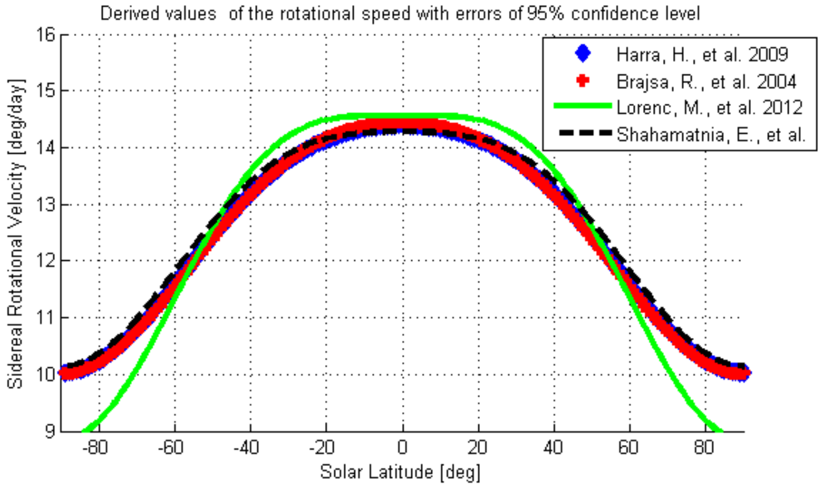


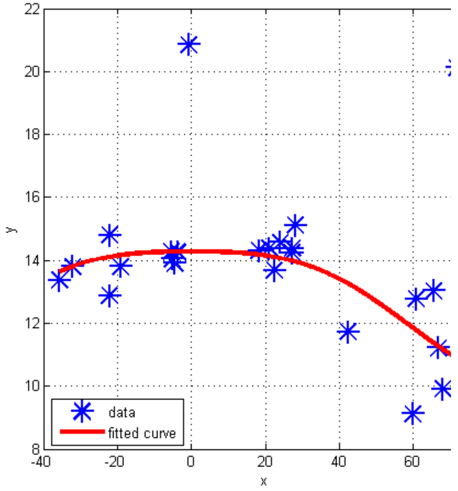
- Calculating the helliographic coordinate and speed of center of BP
- Angular velocity of the earth and data from ephemerids
- Calculate omega at 95% confidence level
- Assumption:
  - No proper motion
  - fixed latitude

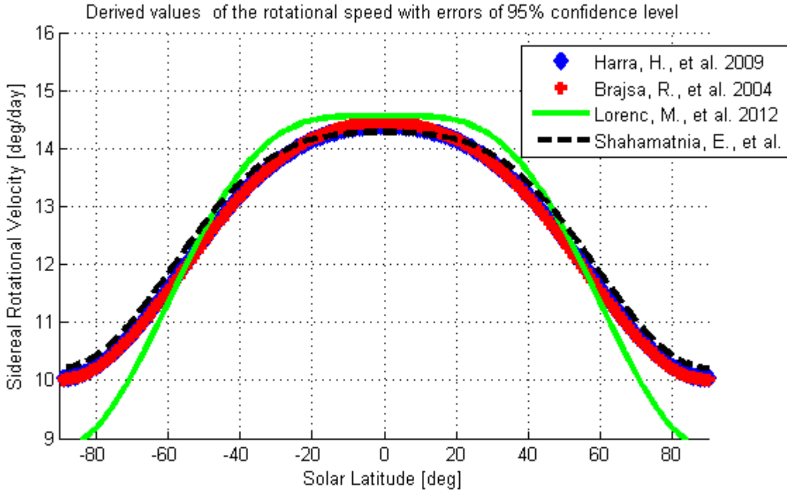
Results

- Levenberg–Marquardt algorithm (LMA) with least absolute residuals (LAR)









Results

	A	B	C
Wohl et al, 2010	14.5	-2.54	-0.77
Brajsa, et al, 2004	14.45	-2.22	-2.22
Lorenc et al , 2012	14.56	0.0	-5.71
This work – 650 measurements	14.2802	-0.6897	-3.4462
This work – 1600 measurements	14.2805	-0.7175	-3.3518

$$w = \mathrm{A} + \mathrm{B}\, sin^2\, \mathrm{b} + \mathrm{C}\, sin^4\, \mathrm{b}$$