Study of Technical Issues Arising in the Tracking Process of Rapid Scan AMV

Kazuki Shimoji

Japan Meteorological Agency/Meteorological Satellite Center

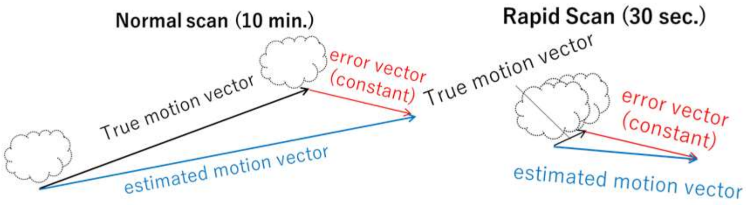
E-mail
kazuki.shimoji@met.kishou.go.jp

1. Introduction

Geostationary meteorological satellites have very high observation time resolution and have the ability to observe a specific area with a time interval of tens of seconds to minutes. Many satellite operators have been attempting to calculate Rapid-Scan AMV from these high-frequency observation data for some time, and JMA is no exception. In calculating Rapid-Scan AMV, there are some technical points to be noted that are different from those of 10- to 15-minute AMV, and the characteristics of Rapid-Scan AMV are also different. This poster introduces those technical issues.

2. Problems arising in RS-AMV

RS-AMV can be expected to calculate high-quality AMVs because of the small changes in cloud shape. However, there is another problem. A typical AMV calculation algorithm measures the amount of cloud displacement between two images based on the pattern matching method and calculates the wind vector by dividing the displacement by the observation time interval. The cloud displacement vector obtained by the pattern matching method includes errors caused by the satellite image alignment process and errors caused by the pattern matching method. If the observation time interval is long, the contribution of the error vector is relatively small because the true cloud motion vector increases in proportion to that time. (See figure below.) However, the opposite is true when the time interval between observations is short. Hence, efforts should be made to reduce the error due to the tracking process.



3. Sub-pixel Tracking

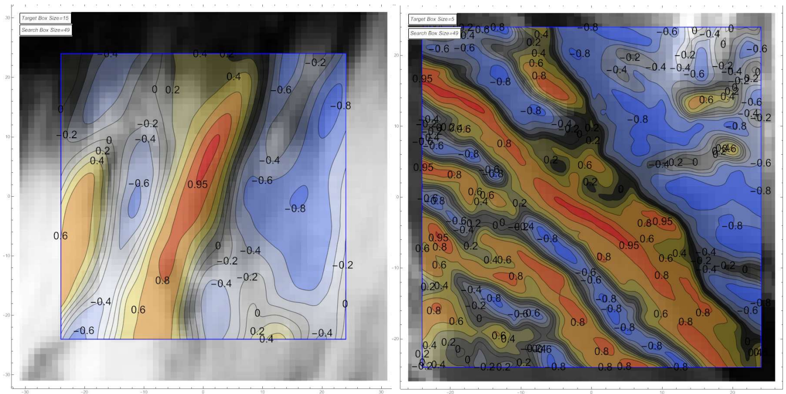
To improve tracking accuracy in RS-AMV, it is important to accurately estimate motion of less than one pixel because of the short time interval between observations. Integer motion vector is too coarse to obtain a practical wind vector. The shorter the time interval of observation, the more accurately it is necessary to estimate the movement of less than one pixel. By using information such as the spatial variation rate of the cross-correlation surface near the pixel with the largest correlation coefficient, the true peak positions can be estimated (interpolated) to estimate the amount of movement of less than one pixel. In JMA/MSC, subpixel estimation has been based on the interpolation method using the following elliptic curve function.

$$C(x,y) = a(x-x_0)^2 + b(y-y_0)^2 + c$$

Since the number of parameters of this fitting function is five, if there are five values around the peak of the correlation surface, all parameters can be determined, and the position of the peak can be estimated in units of less than one pixel. This method has been used at JMA since around 1980, and as far as I have been able to ascertain, other AMV providers use the same method.

4. Correlation surface in reality

Do the elliptic functions currently used for parabolic fit successfully approximate the shape near the peak of the real-world correlation surface? The following are two samples of real-world correlations surfaces. parabolic fit itself certainly appears to be a good model. However, the elliptic functions currently used in sub-pixel tracking cannot represent ellipses with tilted axes. In realistic situations where the axis of the ellipse is tilted, some degree of error is expected to exist.

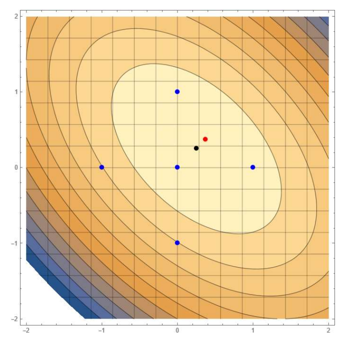


Example of actual correlations surface calculated during AMV derivation. The left figure is for a target box size of 15, and the right figure is for a target box size of 5.The correlation surface near the peak can be approximated by a parabolic fit, but its axis is generally inclined in a discrete direction and is not related to the target box size.

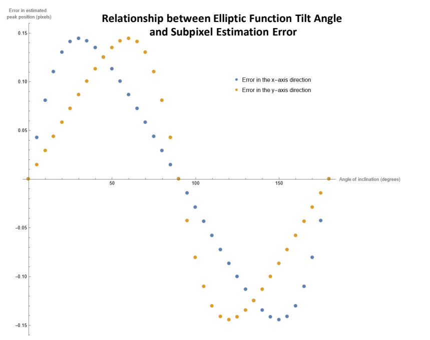
5. Estimating potential errors in current sub-pixel tracking method

How can we estimate the potential error in current sub-pixel tracking methods? We can estimate the extent of the potential error by creating a correlation surface that follows a fitting model that can represent the slope of the ellipse axis, and then using the current sub-pixel estimation process to find the position of the peak and calculate the difference from the truth.

The following figures show the experimental results. The results show that the current sub-pixel estimation process can produce an error of about 0.15 pixels, depending on the direction of the "mountain. This is not negligible in the development of AMVs, and appropriate countermeasures should be taken.



Contour plot of an elliptic function with the true peak at (1/4,1/4) and an eccentricity of 0.8165, rotated 45 degrees around the peak position, considered as the true correlation surface. The black dots represent the true peak position, the red dots represent the estimated position of the peak obtained by the current method (which does not take the axis tilt into account), and the blue dots represent the position of the correlation coefficient used for the estimation. The red and black dots do not coincide.



The graph shows how the peak position estimation error changes when the angle of inclination of the axis of the ellipse is changed, using the same settings as in the figure on the left. It can be seen that estimation error of about 0.15 pixels is generated depending on the angle of inclination.

6. Considerations and future plan

Assuming Himawari's infrared and water vapor AMVs, an error of 0.15 pixels corresponds to 0.5 m/s in SSP for normal 10-minute AMVs using full disk satellite imagery, and 2 m/s for 150-second RS-AMVs using satellite imagery for target observations. The error due to the fitting model for subpixel tracking is considered to be of non-negligible magnitude not only for RS-AMVs but also for regular AMVs. One possible improvement would be to add a term expressing the axis inclination to the fitting model as shown below, and to obtain the parameters by fitting using the least-squares method.

$$C(x,y) = a(x-x_0)^2 + b(y-y_0)^2 + c$$
$$+d(x-x_0)(y-y_0)$$

JMA intends to apply this change in the next algorithm update.

Reference:
J.Ichizawa 1983: A History of the Satellite Wind Estimation at MSC and the Present Accuracy of Satellite Winds, Meteorological Satellite Center Tech Note No.8 September 1983
K.Shimoji 2017: Introduction to the Himawari-8 Atmospheric Motion Vector Algorithm, Meteorological Satellite Center Tech Note No.62 March 2017