Multi-scale image matching for deriving surface velocity field from sequential satellite images

24th Annual Louisiana Remote Sensing and GIS workshop, April 8, 9, and 10, 2008
New Orleans, Louisiana

Lei Wang
Louisiana State University

Hongxing Liu and Sheng-jung Tang
Texas A&M University

Ken Jezek
Ohio State University
Outline

- Feature tracking and image matching techniques in general
- Problems in the conventional methods
- Multi-scale image matching method
- Application example
- Future research opportunities
Feature tracking for change detection

Feature at time $t_1$

Conjugate point $P_1$

$\Delta d$

Feature at time $t_2$

Conjugate point $P_2$
Velocity measured by feature tracking

\[ \Delta d = \sqrt{\Delta x^2 + \Delta y^2} \]

\[ \theta = \tan^{-1}\left(\frac{\Delta y}{\Delta x}\right) \]

\[ v = \frac{\Delta d}{t_2 - t_1} \]
Cross correlation between two images

\[ r = \frac{\sum_{m} \sum_{n} (A_{mn} - \bar{A})(B_{mn} - \bar{B})}{\sqrt{\left(\sum_{m} \sum_{n} (A_{mn} - \bar{A})^2\right)\left(\sum_{m} \sum_{n} (B_{mn} - \bar{B})^2\right)}} \]
Image matching from cross-correlation

\[ r = \frac{\sum_m \sum_n (A_{mn} - \bar{A})(B_{mn} - \bar{B})}{\sqrt{\left( \sum_m \sum_n (A_{mn} - \bar{A})^2 \right) \left( \sum_m \sum_n (B_{mn} - \bar{B})^2 \right)}} \]

Highest r value

r value surface
Feature tracking by image matching

Starting from feature point \( P_1 \) \((x_1, y_1)\) from image \( M_1 \)

Set a Search Radius \( S_r \)

Use image matching to find the conjugate feature point \( P_2 \) \((x_2, y_2)\) in image \( M_2 \) within \( S_r \)

Calculate \( \Delta x, \Delta y \)

Calculate \( \Delta d, v, \) and angle
Problems with the conventional methods

- If $S_r$ is set to small (e.g. less than the moving distance), the search method cannot find the correct conjugate point because it is not in the range to be considered as matching candidate.

- To guarantee the conjugate point is included in the search window, the $S_r$ is normally set to a large value.
Problems with the conventional methods

- The search computation complexity is to $O(S_r^2)$, where $O(.)$ can be regarded as “proportional to”. Therefore, a too large search radius will be very inefficient.
- A large search radius also would introduce a “false match”, because it increases the chance to include multiple similar features located at other portions of the image.
From prior knowledge, predict an approximate conjugate point $P'_2$ by giving a $x_{\text{offset}}$ and a $y_{\text{offset}}$.

Starting from $P'_2$, use a small search radius $S_r'$ to find the true conjugate feature point $P_2 (x_2, y_2)$ in image $M_2$ within $S_r'$.

If the $x_{\text{offset}}$ and $y_{\text{offset}}$ is chosen correctly, the matching points can be reliably located by using a small search radius.
Problems still exist

- $x_{\text{offset}}$ and $y_{\text{offset}}$ are arbitrarily given, if their values are wrong, the matching results will be wrong.
- Only one set of $x_{\text{offset}}$ and $y_{\text{offset}}$ can be given for one region, if the feature moving speed varies much with this region, the matching can only be satisfactory in a limited portion of the image.
Area A

Area B

feature movement vectors

Matched results using $x_{offset} = 1000$ m, $y_{offset} = 625$ m

Matched results using $x_{offset} = 2500$ m, $y_{offset} = 1500$m

Green dots are feature points, yellow lines indicating moving distance and direction
All the above image matching used 750 m as search radius
A Multi-scale approach

At the top of the image pyramid, the search radius has been extended to 8 times (level = 4) to the finest resolution. A very small search radius can be used in this approach.
A Multi-scale approach

Create Gaussian image pyramid \((G_0, G_1, \ldots)\)

Run image matching at current level (starting from level 3)

Automated error checking

Interpolate and use as the predicted \(x_{\text{offset}}\) and \(y_{\text{offset}}\)

Finest Resolution?

Write to output
Progressive improvement of conjugate point position
Matched results using the multi-scale approach

Matched results using $x_{\text{offset}} = 1000$ m, $y_{\text{offset}} = 625$ m

Matched results using $x_{\text{offset}} = 2500$ m, $y_{\text{offset}} = 1500$ m

Green dots are feature points, yellow lines indicating moving distance and direction
All the above image matching used 750 m as search radius
Implementation in ArcGIS and MS Visual Studio environment
Application example: SAR images acquired in 1997 and 2000 in Antarctica

- Rigorously orthorectified
- Spatial Resolution 25 m
- Covers the ground area about 308.4 km × 193.9 km
- 5×5 Lee filter to reduce noises and speckle
Matching result – surface motion vectors
Matching results – Velocity field
Matching results – surface motion direction and pattern
Conclusions

- Conventional methods for image matching can only be effective for areas with a relatively small range of motion velocity variation.
- The progressive search for conjugate points in multiple scales takes advantage from both coarser resolution (large cover area) and fine resolution (location accuracy) images from the image pyramid.
- Our multi-scale, hierarchical image matching utilized smaller search range comparing to conventional methods, therefore can achieve better computation efficiency and matching accuracy.
Future research

- Interactive methods (include more human controls) to provide better interface and functions
- Develop to a distributable software package
- Other fields for application (sand dunes, river channels, ocean waves, clouds)