www.nr.no

A system for adaptive image registration based on supervised learning

Line Eikvil, Marit Holden, Ragnar B. Huseby

Norsk Regnesentral

ESA-EUSC IIM Workshop
Madrid, Nov. 4, 2009

Agenda

Background

- The analysis of time series of remote sensing images require that the images are co-registered.
- Manual co-registration is tedious.
- Automatic techniques exist, but:
  - selection of the right technique depends on the application and the image specifics,
  - and a single registration technique will generally not be sufficient when handling a range of images.
- For a user that needs to work on different types of time series, it would therefore be useful to have a more general tool for image registration.

Projects

- MIR (April 2004 - June 2005)
  - Initial development of methods and software
- MIR extension (Nov 2006 – March 2009)
  - Validation, improvement and extension.
  - Incorporation in KEO

The MIR approach

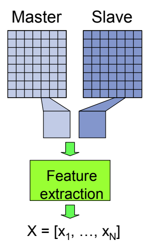
- The MIR system consists of:
  - A library of registration algorithms
    combined with
  - Methodology enabling automatic algorithm selection based on image characteristics.
- The approach is based on supervised learning
- It is made locally adaptive by using a region-based strategy.

Automatic algorithm selection

- Region-based feature extraction
  - Divide images into regions
  - Extract region features
- Performance prediction
  - For each region, predict the registration performance for each of the available algorithms.
- Region and algorithm selection
  - Select the regions to be used
  - Select the algorithm to be used for the selected regions.

Feature extraction

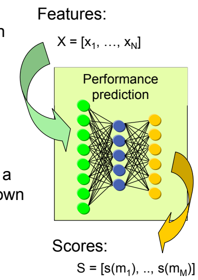
- Features are extracted from a pair of regions
- Features are selected to say something about:
  - The information content in the region
  - Difference between master and slave
- For this a set of features based on image texture and image statistics have been selected.
- These are merged into a joint feature vector.



Norsk Regnesentral

Performance prediction

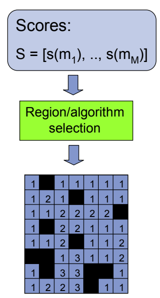
- A neural net is used to predict the performance of the different registration algorithms from the features.
- The net is defined as follows:
  - N input nodes (N = nof features)
  - One layer of hidden nodes
  - M output nodes (M = nof algorithms)
- The net is pre-trained on features from a large set of image/region pairs with known geometric displacement.



Norsk Regnesentral

Region and algorithm selection

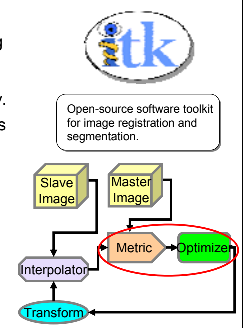
- Selection of regions:
  - Regions with low scores are discarded.
  - For the remaining regions, selection is performed to retain a good distribution over the image.
- Selection of algorithms:
  - For each selected region the algorithm with the best score is selected.
- Result:
  - A set of regions with a corresponding choice of registration algorithm.



Norsk Regnesentral

Library of algorithms

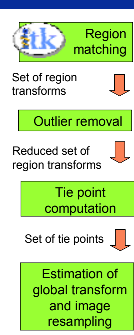
- MIR works on top of a set of existing registration algorithms.
- The set consists of a selection of algorithms from the itk/Insight library.
- We define a registration algorithm as a combination of a metric and an optimizer.
- 10 combinations of the following metrics and optimizers are used:
  - Metrics: Normalized cross-correlation, mean squares and mutual information.
  - Optimizers: Gradient descent, regular step gradient descent and a genetic algorithm.



Norsk Regnesentral

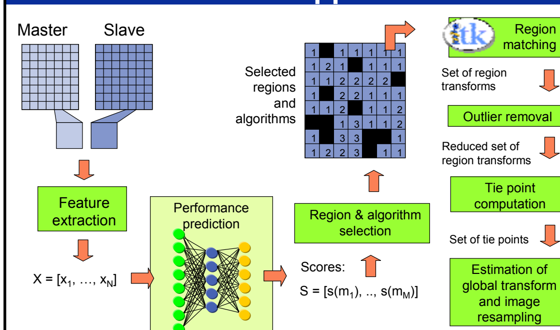
Registration

- Perform local registration
  - The selected registration algorithms are used to estimate the transform for each of the selected regions.
- Identify and remove outliers
  - The set of estimated transforms is analysed to remove obvious outliers.
- Perform global transform estimation
  - Determine tie points from the local registrations.
  - Use these to estimate the global transform.
  - Resample the image.



Norsk Regnesentral

Overview of MIR approach



Norsk Regnesentral

Summary of MIR approach

- The MIR approach uses a learning-based strategy:
  - During a training phase the system learns the relationship between image characteristics and performance for different registration algorithms.
- The MIR approach is locally adaptive:
  - The learning-based strategy is applied to image regions.
- This enables:
  - identification of regions suited for registration.
  - selection of an appropriate algorithm for these region.
  - rejection of regions unsuited for registration.

Quality indicators (QI)

- Computed to give an indication of the quality of the result, without having to investigate the images.
- The quality indicators are computed from:
  - the control points (tie points).
    - *Control point gap* indicates how well these are distributed over the image.
    - *Control point RMS* gives mean distance between the transform for each control point and the global transform.
  - the mutual information between the images before and after registration.
    - A high MI value means a high dependency/similarity, and the MI between two images is expected to increase after co-registration.

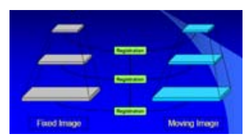
Quality indicators – Example

Correspondence with RMS

Image Pair:	Very similar Medium dist.		Very similar Large dist.		Quite different Medium dist.		Quite different Large dist.	
Distortion:	*T8*	*R1*	*T50*	*R8*	*T8*	*R1*	*T50*	*R8*
Control point gap	0.025	0.022	0.023	0.067	0.134	0.130	0.147	0.149
Control point RMS	0.115	0.189	16.897	4.055	0.400	0.393	3.632	3.324
Initial mean MI	0.369	0.542	0.302	0.331	0.266	0.303	0.254	0.263
Resulting mean MI	2.625	1.985	0.306	0.327	0.402	0.407	0.263	0.273
MI improvement	2.256	1.442	-0.003	-0.004	0.137	0.104	0.010	0.010
RMS error	***0.02***	***0.06***	***72.55***	***54.39***	***0.21***	***0.21***	***73.77***	***54.45***

MRR - Multiresolution registration

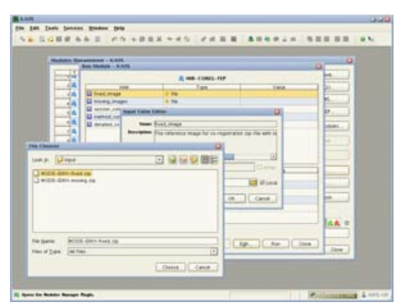
- **Purpose**
  - Used in MIR to be able to handle larger distortions.
- **Principle for multireolution registration**
  - Registration is first performed at a coarse scale where the images have fewer pixels.
  - The mapping determined at the coarser level is then used to initialize registration at the next and finer scale.
  - The process is repeated until it reaches the finest scale.



Strategy for MRR in MIR

- Overall strategy
  - MRR used as a preprocessing step to obtain an initial coarse registration.
  - The adaptive MIR approach is used at the finest resolution level to refine the result.
- MRR strategy
  - Applied to the entire image (no regions).
  - The same method at each resolution level.
  - The choice of method is predefined (not adaptive).

Integration in KEO



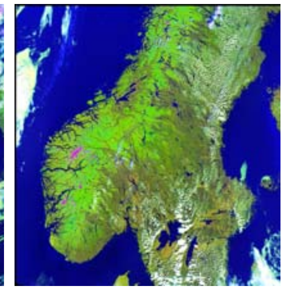
www.nr.no

Results

- ► **Selection of regions**
- ► **Selection of algorithms**
- ► **Registration accuracy**
  - ▪ Evaluation procedure
  - ▪ Medium-sized distortions
  - ▪ Large distortions

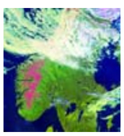
NOAA-AVHRR

May 31, 2003

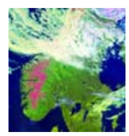


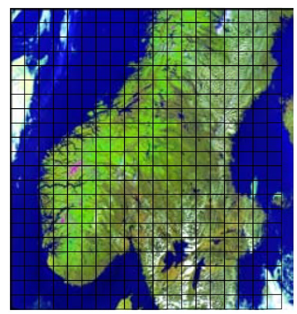
July 7, 2003

NOAA-AVHRR

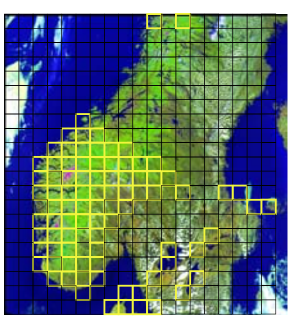


NOAA-AVHRR: Regions

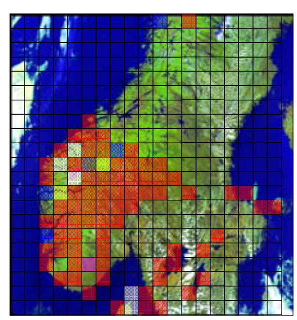




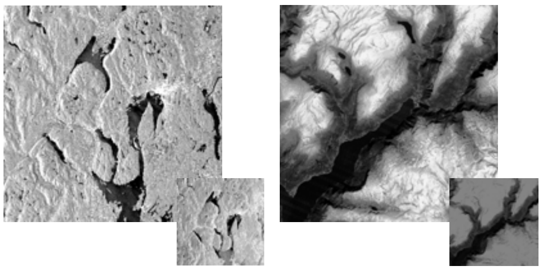
NOAA-AVHRR: Region selection



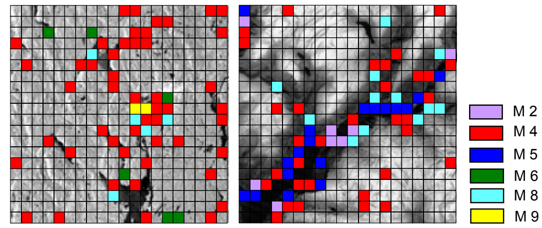
NOAA-AVHRR: Algorithm selection



ASAR & Landsat



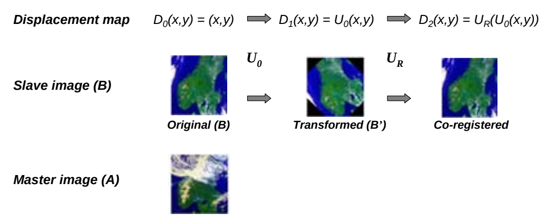
ASAR & Landsat: Algorithm selection



Evaluation procedure

- Two initially (manually) co-registered images, A and B.
- Apply a known transformation, U_0, to B, obtaining B'.
- Co-register A and B', resulting in an estimated transformation U_R of B'.
- Ideally, U_R should equal U_0^{-1}.
- Measure the quality of the registration by the RMS residual differences between U_0^{-1} and U_R.
  - …or equivalently their corresponding displacements.

Evaluation procedure



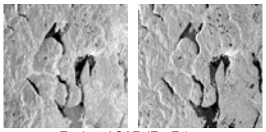
Set of images

- Tests performed for several degrees of difficulty in terms of changes in scene appearance:
  - Images with no differences in content
  - Images with moderate differences
  - Images with large differences
- Tests performed for a set of known displacements:
  - Translations, rotations, scalings and combinations of these.

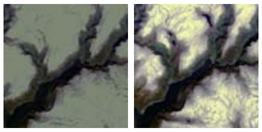
No differences in content

QuickBird (QB)

Moderate differences in content



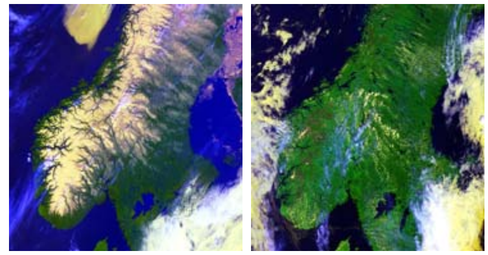
Envisat ASAR (E_1, E_2)



Landsat (L_1, L_2)

NOAA-AVHRR (N_1, N_2)

Large differences in content

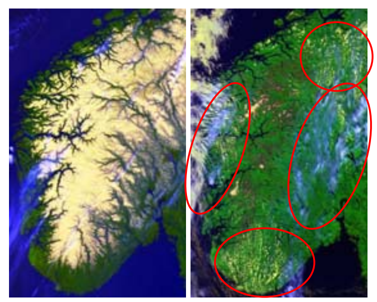


NOAA-AVHRR (N_2, N_3)

Registration accuracies

	No diff	Moderate differences			Large diff	
Distortion	*QB*	*E1, E2*	*L1, L2*	*N1, N2*	*N2, N3*	
Identity	0.00	0.54	0.92	0.51	0.47	0.25
T2	0.04	0.54	0.97	0.53	2.00	0.60
T4	0.05	0.57	0.94	0.56	3.05	0.85
T8	0.04	0.53	1.03	0.54	10.24	0.53
S .5%	0.05	0.53	0.99	0.54	1.00	0.45
S 1%	0.04	0.46	1.01	0.58	2.76	0.76
S 2%	0.12	0.50	0.90	0.67	5.19	0.85
R .25°	0.03	0.51	1.01	0.52	1.65	0.47
R .5°	0.05	0.51	0.99	0.58	2.41	0.53
R 1°	0.09	0.48	0.93	0.63	7.55	1.38
T 2/S .5%/R .25°	0.04	0.49	0.98	0.56	2.06	0.75
T 4/S 1%/R .5°	0.07	0.53	1.01	0.60	5.03	5.78
RMS mean	**0.06**	**0.52**	**0.97**	**0.57**	**4.55**	**1.81**

Large differences: Unsuited areas



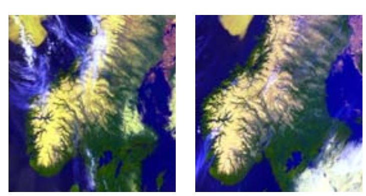
NOAA-AVHRR (N_2, N_3)

Summary of results

- Subpixel accuracy verified for perfect conditions.
- Subpixel accuracy also for images with moderate differences in contents.
  - Consistent results indicate better performance than for manual registration.
- Example with large differences in content:
  - Variable performance.
  - Mainly due to a large number of unsuitable areas?

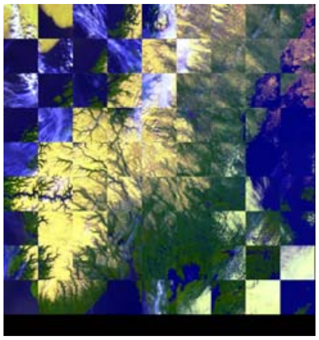
Example for large distortions

- NOAA-AVHRR image pair
  - Results with and without MRR



Translation 40 pixels
Scaling 8%
Rotation 4°

Image mosaic – before registration

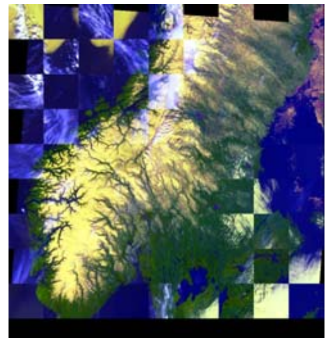


Translation 40 pixels

Scaling 8%

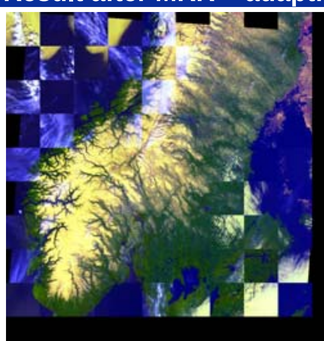
Rotation 4°

Result after MRR only



RMS error: 0.68

Result after MRR + adaptive



RMS error: 0.53

Summary of results

- The adaptive co-registration without MRR is the most accurate.
- The multiresolution registration is necessary for registration of image pairs with large distortions.
- The multiresolution registration is less robust for large differences or large areas covered by clouds.

Summary

- The MIR approach:
  - Based on a learning-based strategy:
    - The system learns the relationship between image characteristics and performance for different registration algorithms.
  - Locally adaptive:
    - The approach is applied to subimages.
  - This enables selection of the best registration algorithm for each region in the image, while regions unsuited for registration can be discarded.
- The MIR system:
  - Facilitates co-registration of time series of images by providing:
    - an adaptive registration with subpixel accuracy
    - automatic run-time selection of the best method.
    - a multiresolution registration option for larger distortions.

Possible future work

- Preparations for operational use on time series.
- Improvements based on user feedback.
- Adaptation and validation for newer libraries.
- Evaluations for multi-sensor.
  - Evaluation of current performance.
  - Evaluation of additional registration algorithms (e.g. wavelet-based, feature-based etc.)
  - Evaluation of features for algorithm selection.