Temporal Resolution Enhancement from Motion
EMRS DTC, Transducer Embedded Processing Theme

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Context

Objectives

- Overall goal:"To exploit a sequence of sensor images in which there is relative motion between sensor and scene to provide an enhanced representation of the scene, such that the spatial (angular) resolution is improved multiplicatively."
- To formulate and solve the high dimensional inference problem efficiently so as to attain real-time performance.
- To demonstrate improved clutter suppression in target acquisition by super-resolving the background scene estimate.

Military benefit

- Temporal Resolution Enhancement (TRE) improves the effective resolution of legacy hardware through software-only upgrade.
- For future systems it enables the use of smaller, lighter and cheaper sensors for a specified level of performance.
- TRE processing software for moving Electro Optic (EO) sensors on aircraft, UAVs and missiles could provide:
  - increased identification range via enhanced resolution target images.
  - enhanced resolution scene images for better clutter suppression in target acquisition, or a better quality surveillance product.
- The TRE technique is also relevant for sensors operating in other wavebands including passive millimetre wave imagers or synthetic aperture radar.

Problem Definition

Inputs to TRE processing:

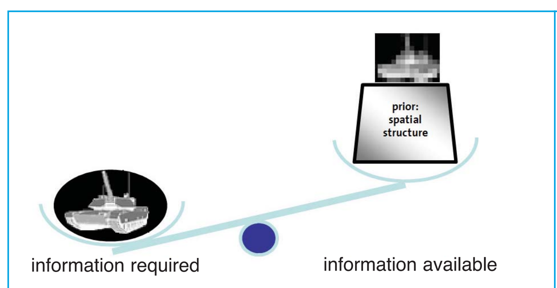
- A sequence of images received frame-by-frame from the EO sensor.
- A description of the sensor (including the optical point spread function, the active area of each detector pixel, and the detector noise characteristics).

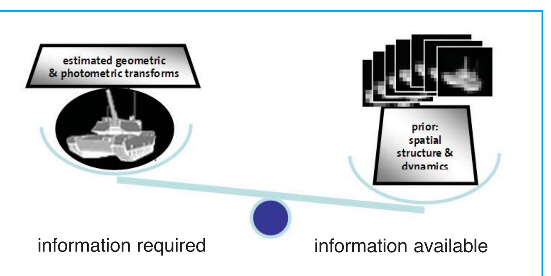
Incorporating additional on-line estimation processes such as blind deconvolution would reduce the reliance on some of these inputs. The work completed in the first year (reported here) is predicated on there being no depth variation in the scene, and thus provides a 'two-dimensional' process.

Output from TRE

- The principal output of the TRE process is a high resolution estimate of the scene, represented as a regular grid of intensities, with the number of grid points being a multiple of the number of pixels in the measurement image.
- The secondary output is the sequence of transforms (geometric and photometric) between successive image frames. This could be used to form mosaic images or as a robust target tracking process.

Temporal resolution enhancement





Single frame super resolution schemes:
- seek to provide an estimate of the scene using a single low resolution (measurement) image.
- are ill conditioned because the amount of information to be inferred is much greater than the amount available. (Spatial structure models were introduced to overcome this difficulty, but there remains a limit to the resolution that can be reasonably achieved).

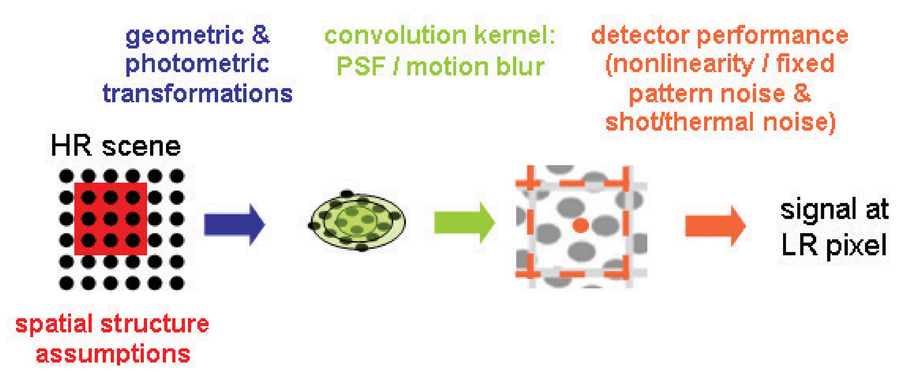
Multi-frame Multi-frame (or temporal) resolution enhancement has 2 advantages:
- there is much more information in a sequence of images than in a single image.
- relative motion between sensor and scene reduces the impact of aliasing and other artefacts.

To exploit the extra available information requires inference of the transformations which relate sequential measurement frames. ie:
- the dynamics of the sensor and the scene (geometric parameters).
- the changes in camera sensitivity and illumination (photometric parameters).

Technical Approach

Model of measurement process

- Relates points in the high resolution scene to pixels in the low resolution (measurement) images.
- Defined by optical effects (such as the point spread function) and sampling effects (detector active area).



Measurement model: relates high resolution scene to pixel values in the (low resolution) observed sensor image.

Inference problem

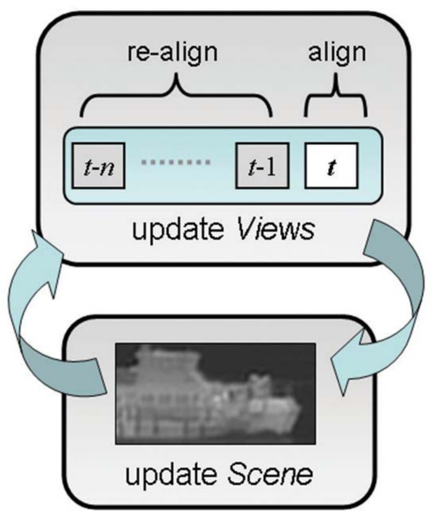
- Bayesian problem formulation.
  - decompose the inference problem and apply methods appropriate to the dimensionality of each part of the problem:
    - scene points ~10^5
    - transformations ~10 parameters x (#frames)
- Address modelling error (many sources) via experimentation with real image sequences.
- C++ implementation to support many variants through object oriented software design. Allows tuning for particular data sources and performance requirements.

Regularisation – spatial structure models

- Techniques considered:
  - linear operators (e.g. Laplacian of Gaussian)
    - fast and effective, especially where detector noise is dominant
  - nonlinear operators (total variation, bilateral-TV)
    - robust in presence of modelling error
  - boundary/feature contour system (multiple competing planes)
- The spatial model becomes less important once TRE has 'bootstrapped'.

Algorithm overview

- Typical mode of operation is "sliding window" processing of a sequence of measurement images.
- On receipt of each new image, perform the following operations :
  - estimate or resample transformations of :
    - latest frame relative to scene
    - previous frames in the time window
  - estimate or resample scene accounting for:
    - measurement images in sliding window
    - prior structure model

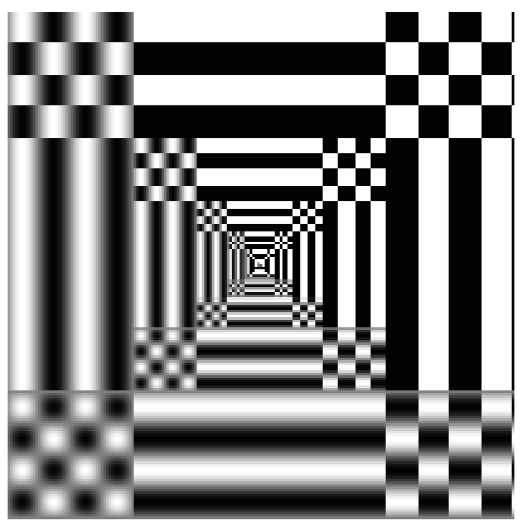


Decomposed inference problem: identify transformations and then update the resolution enhanced scene estimate.

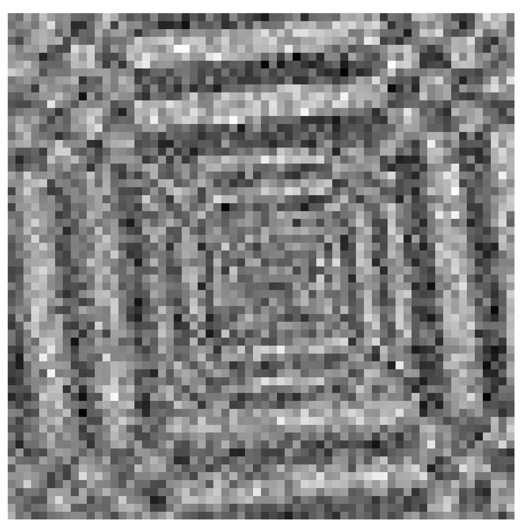
Results

Synthetic data.

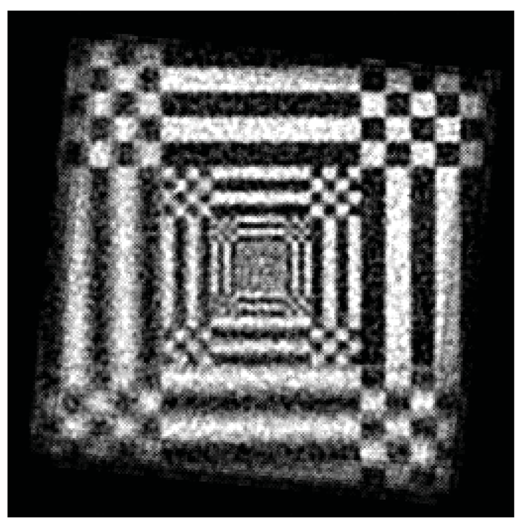
- TRE performance produces a factor of 2 resolution improvement in each direction - approaches the information theoretic bound (i.e. resolution improvement scales as square root of frame count).
- This upper bound will not be reached if there is insufficient motion (in each axis); insufficient structure for accurate registration; or modelling error.



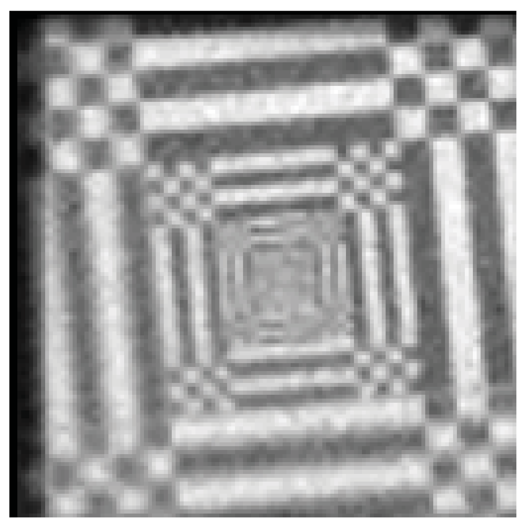
Test scene-An analytic function



Exemplar measurement image.



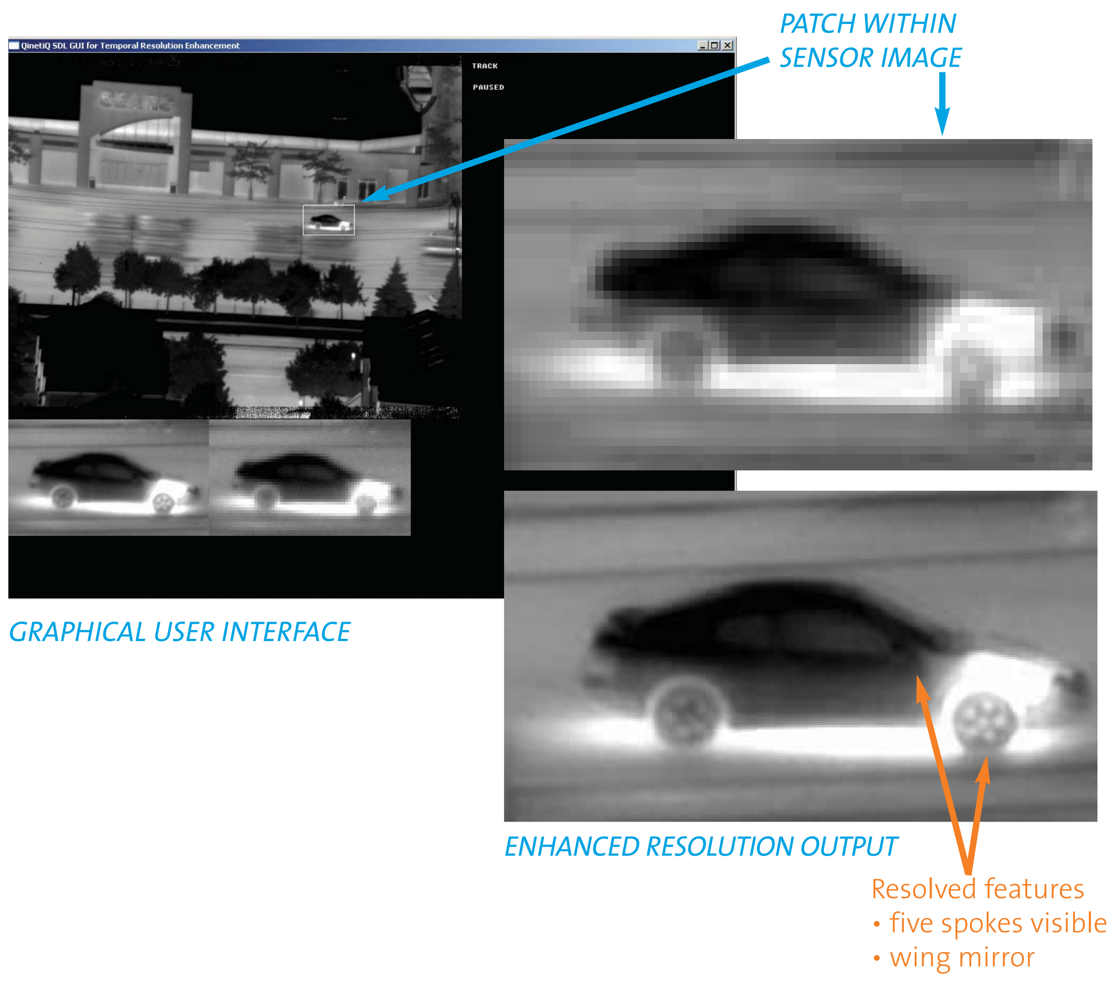
TRE output-using 17 measurement images.

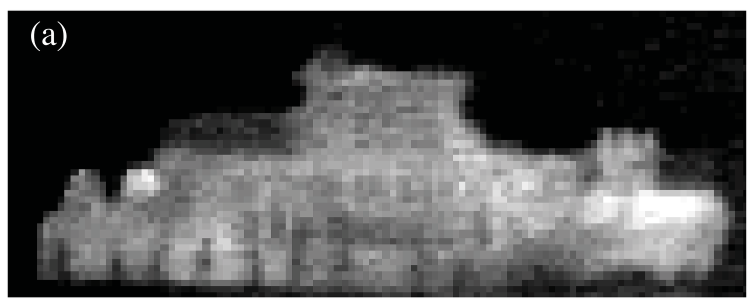


Temporal averaging result-integer pixel alignment and summation of the measurement images.

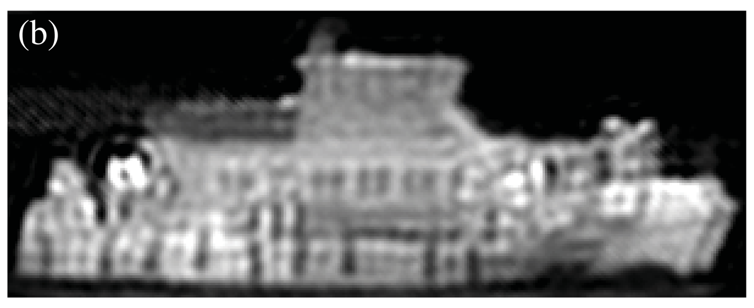
Real data – Case study 1, Infra red imagery

- Results are presented for two IR image sequences
  - a car (sequence supplied by L-3 WESCAM).
  - a harbour ferry (sequence supplied by DEC AWE AIMMS).
- The TRE result clarifies details such as the number of spokes in the car's front wheel and the shape of the hull, that were not visible in the source imagery, even when viewed as a sequence.





SINGLE SENSOR RESOLUTION IMAGE FRAME



TRE PROCESSING OUTPUT AFTER 100 FRAMES

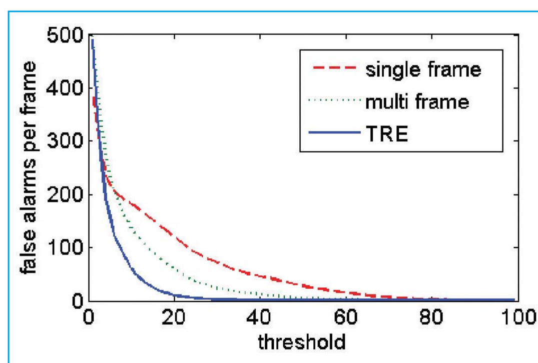
Real data - Case Study 2 Clutter suppression in target acquisition

Context

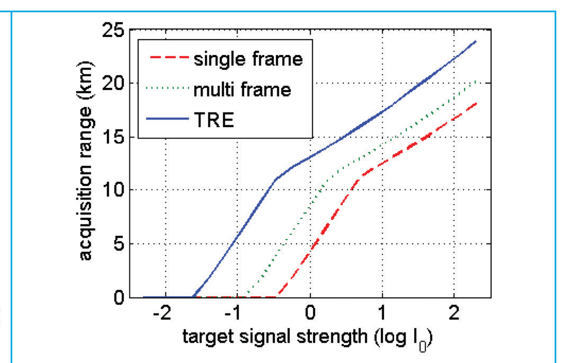
- Imaging missile seeker acquisition range usually limited by clutter, not noise.
- DEC TA research has shown benefits for target detection of on-line backgournd (clutter) estimation (targets are outliers).
- Apply TRE to clutter background to obtain a more accurate clutter estimate.
- These results were produced using ground-based seeker data collected at 2006 Farnborough International (and made available with MOD permission).

Experimental Method

- Extensive preprocessing, including insertion of a (single pixel) reference target at fixed signal level.
- Target detection process.
  - subtract a background estimate if applicable.
  - non-maximal suppression + CFAR threshold (10 events per frame).
- Compare 3 methods to obtain input to detection process:
  - single frame maxima.
  - background registration to nearest pixel.
  - TRE background scene estimation and reprojection.



Receiver operating characteristic comparison : False alarm vs threshold for three schemes of target acquisition.



Increase in acquisition range : Acquisition range vs target signal strength for three schemes of target acquisition.

- Implications of receiver operating characteristic for acquisition range predicated upon:
  - nominal constant false alarm rate (10 per frame).
  - assumed physical model that relates target signal strength to range (taking account of atmospheric attenuation and sub-pixel effects).
- Indicative performance only - analysis performed on one data sequence.

- *Conclusions*
  - Multi-frame integration has major clutter suppression benefit.
  - Super-resolved background model further suppresses clutter.
  - Implies a major improvement in acquisition range, typically >50%.

Summary

- We have developed a flexible framework for temporal resolution enhancement with broad applicability to a variety of tasks including acquisition and target identification.
- We have focused on efficient decomposition of the inference problem, and on addressing the modelling error that is inevitable when working with genuine sensor image sequences.
- The algorithm has been shown to be effective for resolution enhancement of maritime and urban targets in imagery from a steered EO turret, as well as for clutter rejection in long range acquisition by a missile seeker.
- Although the evaluation has been limited to IR imagery, similar gains are expected in other passive imaging sensors.

