Image Fusion Using Belief Propagation

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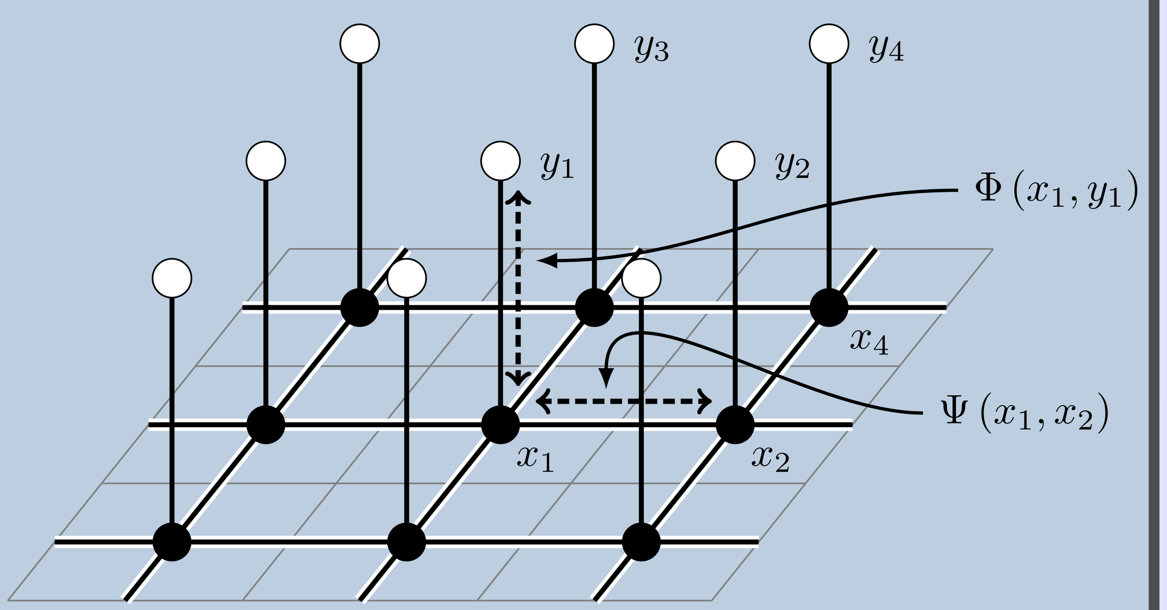
Introduction / Contributions

- Application of belief propagation methods to image fusion.
- Fusion within a complex wavelet decomposition (DT-CWT).
- Belief propagation within each transform subband iterates through a lattice based Bayesian belief network.
- Precisely controlled spatial coherence of subband coefficient fusion through the definition of belief graph probabilities.
- Significant improvement in quantitatively measured fusion performance for over 160 fusion image pairs.
- Tested using a range of fusion applications including remote sensing, multi-focus and multi-modal sources.
- Improvements in qualitative image fusion performance is also demonstrated.

BP based Fusion



Bayesian Graph Model for Belief Propagation within a single wavelet subband (the black dots represent the hidden states (x) and the white dots represent the observations (y)). The probability of the choice of one image coefficient (out of the two possible) is proportional to the product of all sets of compatibility matrices Ψ and vectors Φ [2,3]:

$$P(x|y) = \frac{1}{Z} \prod_{(i,j)} \Psi_{ij}(x_i, x_j) \prod_i \Phi_i(x_i, y_i). \quad (4)$$

This is difficult to evaluate for any non trivial case. BP uses a message-passing system that updates "messages" $\boldsymbol{m_{ij}}$ from hidden node x_i to x_j. These "messages" are two dimensional vectors updated using [2,3]:

$$m_{ij}(x_j) = \sum_{x_i} \Psi_{ij}(x_i, x_j) \prod_{k \neq j} m_{ki}(x_i) \Phi_i(x_i, y_i). \quad (5)$$

When this iterative update has converged, the BP estimate of the marginal probability vector $\boldsymbol{b_i}$ can be found using:

$$b_i(x_i) = \prod_k m_{ki}(x_i) \Phi_i(x_i, y_i), \quad (6)$$

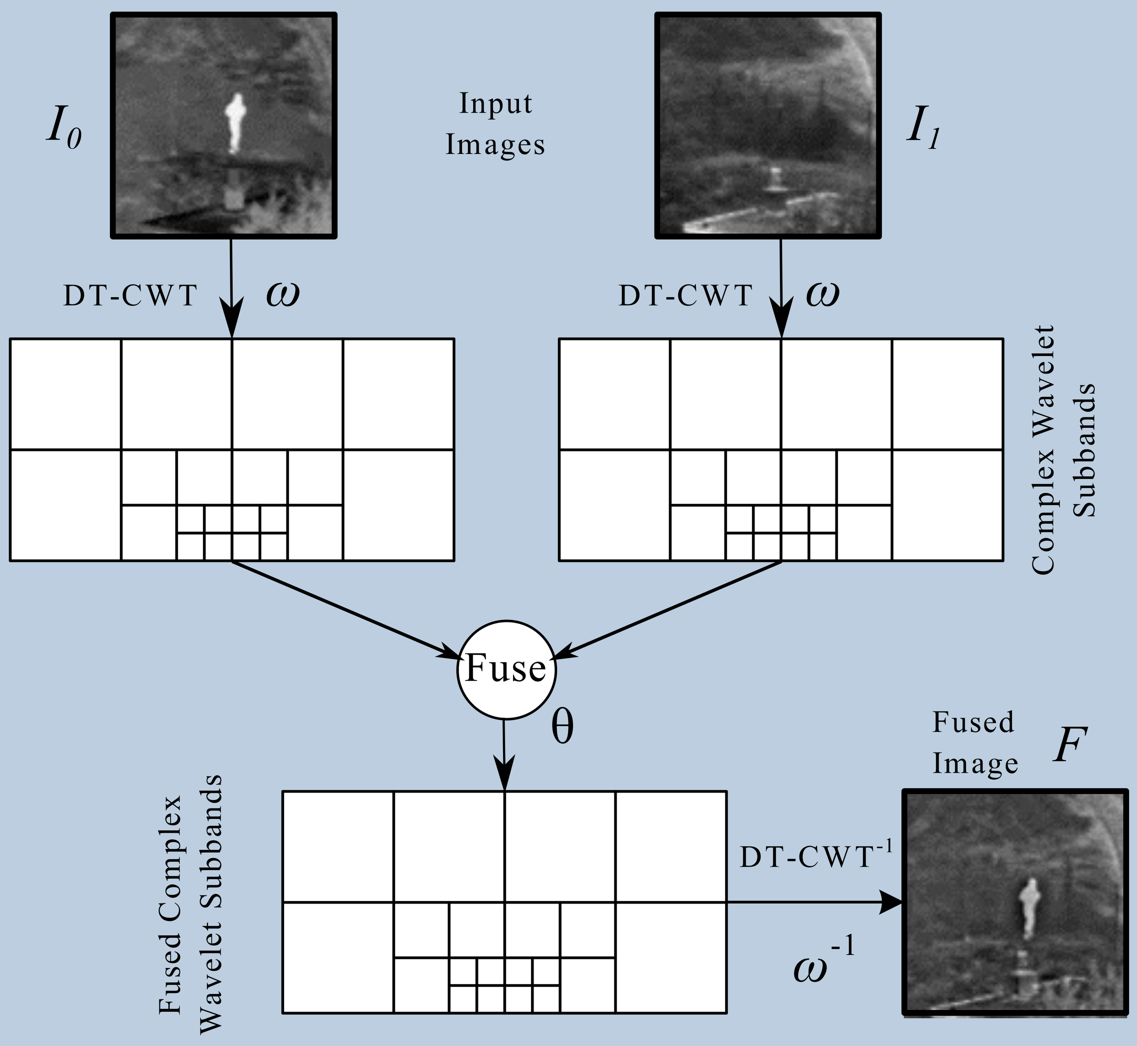
where $b_i(x_i)$ is the component of $\boldsymbol{b_i}$ associated with image coefficient x_i. The MAP estimate for the output coefficient x_{jMAP} can be chosen as the maximum component within $\boldsymbol{b_i}$

$$x_{jMAP} = \text{argmax}_{x_j} b_i(x_i), \quad (7)$$

Wavelet Image Fusion

Fusion of two sources using the DT-CWT is defined in terms of the two registered input sources $\boldsymbol{I_0}$ and $\boldsymbol{I_1}$, the wavelet transform itself $\boldsymbol{\omega}$ and a fusion rule $\boldsymbol{\theta}$. The fused wavelet coefficients are then inverted using an inverse wavelet transform $\boldsymbol{\omega^{-1}}$ to produce the resulting fused image $\boldsymbol{F}$:

$$\boldsymbol{F} = \boldsymbol{\omega}^{-1}(\boldsymbol{\theta}(\boldsymbol{\omega}(\boldsymbol{I_0}), \boldsymbol{\omega}(\boldsymbol{I_1}))). \quad (1)$$



Compatibility Functions

$$\Phi_k(x_k, y_k) = \exp\left(-\frac{d(x_k, y_k)}{2\sigma^2}\right) \quad (2)$$

where $d(x_k, y_k)$ is a distance measure between the hidden state x_k and its associated observation y_k. This is defined as $d(x_k, y_k) = S_{max} - |c_k|$ where $|c_k|$ is the magnitude of the subband coefficient c_k and S_{max} is the maximum of $|c_k|$ for both image subbands.

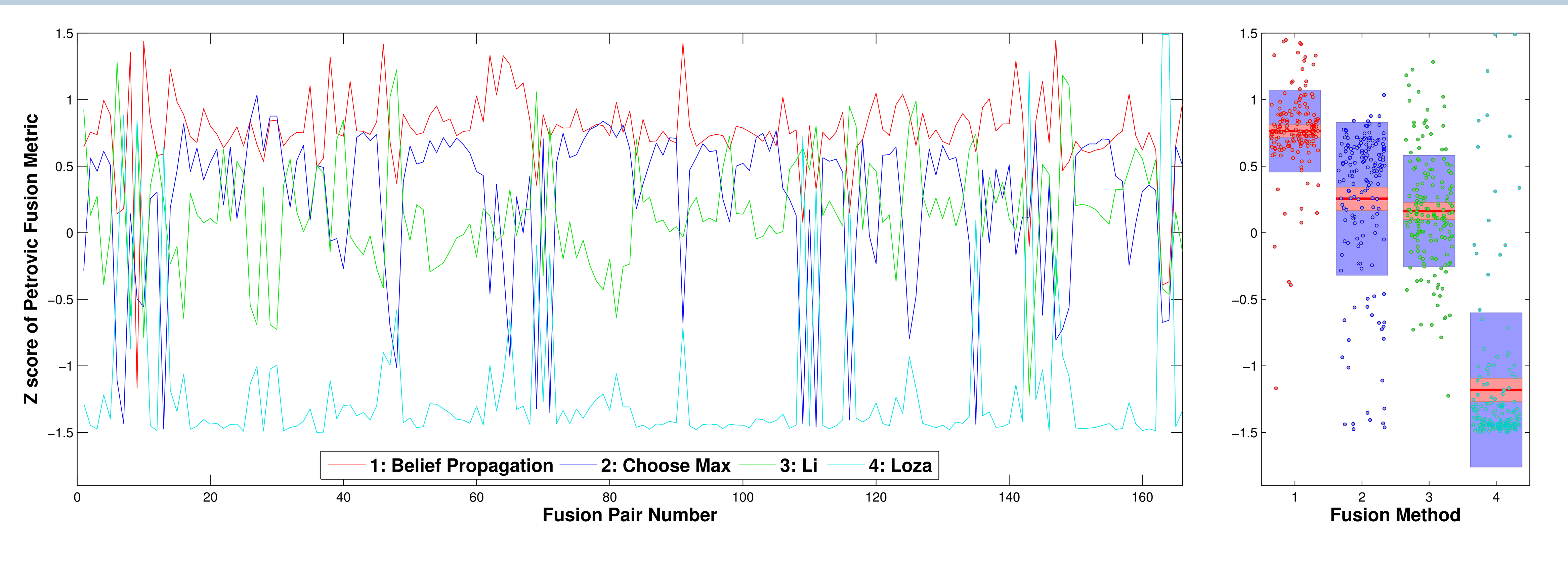
Ψ is matrix valued with the elements representing the compatibility of a hidden state x_i with its neighbour x_j:

$$\Psi = \begin{bmatrix} \Psi_{11} & \Psi_{12} \\ \Psi_{21} & \Psi_{22} \end{bmatrix}, \quad (3)$$

where $\Psi_{11} = \Psi_{22} = \rho$ and $\Psi_{12} = \Psi_{12} = 0$. Ψ can be defined separately for each of the 4-connected directions according to application requirements. However, they are defined as being equal within our two image fusion case.

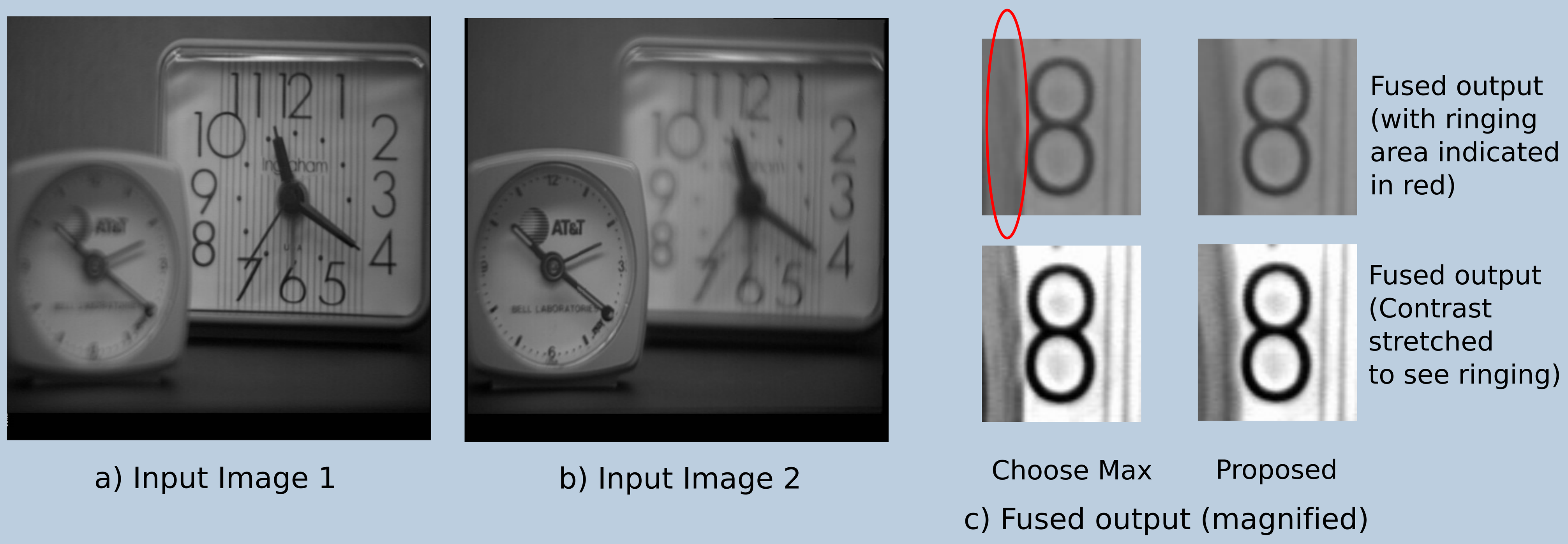
ρ is set to be 0.3679, Ψ is now the identity matrix I_2. σ is set to 0.1342 for all the experiments. The optimisation method to obtain these value was the default simplex method used within the MATLAB `fminsearch` function.

Results: Z Score Results for Petrovic Metric



Z score results for Petrovic Metric (166 image fusion pairs (indexed on the x axis). [1])

Results: Multifocus Example Fusion



a) Input Image 1   b) Input Image 2   c) Fused output (magnified)

Ringing artefacts can be seen to the left of the letter 8 in the choose maximum fused image compared to the proposed fused image.

Conclusions

- Flexible method to control spatial coherence of image fusion
- Improvement in quantitatively measured fusion performance for over 160 fusion image pairs
- Improvements in qualitative image fusion performance is also demonstrated

References

[1] V. Petrovic, *Subjective tests for image fusion evaluation and objective metric validation* Information Fusion, vol. 8, no. 2, pp. 208-216, 2007.

[2] W.T. Freeman, E.C. Pasztor, and O.T. Carmichael, *Learning low-level vision* International journal of computer vision, vol. 40, no. 1, pp. 25-47, 2000.

[3] J. Besag, *Spatial interaction and the statistical analysis of lattice systems*, Journal of the Royal Statistical Society. Series B (Methodological), pp. 192-236, 1974.