3D normalized cross-correlation for estimation of the displacement field in ultrasound elastography

Morteza Mirzaei[a,*], Amir Asif[a], Maryse Fortin[b], Hassan Rivaz[a,b]

[a]*Department of Electrical and Computer Engineering, Concordia University, Montreal, Quebec, Canada*
[b]*PERFORM Centre, Concordia University, Montreal, Quebec, Canada*

This supplementary material contains more analysis on how the STNCC (Spatial Temporal normalized Cross Correlation) outperforms NCC (normalized Cross Correlation) for different data sets with high and low SNR.

High SNR::

STNCC improves temporal behavior of the estimated strains for high SNR data significantly. Temporal accuracy plays an important role in poroelastic elastography [1], viscoelasticity measurment of the tissue [2], dynamic elastography methods such as shear-wave elastography [3, 4] and vibro-elastography [5]. To show improved temporal behavior by STNCC, we consider three frames for NCC and three sets of frames for STNCC as shown in Fig.1. The displacement for each pair is calculated and the difference of estimated displacement is calculated as acceleration for both NCC and STNCC method. We calculate acceleration for phantom data with high SNR (without adding noise) and the results are shown in Fig.2. The low acceleration of STNCC clarifies improved temporal behavior by STNCC.

Low SNR:

For low SNR, not only STNCC improves temporal behavior, but also it generates more accurate and robust strain fileds as it is reported in the main manuscript. Also, STNCC performs better than estimating TDE for 2D RF data and averaging them since averaging strain field as a post processing algorithm can reduce the error by smoothing, but it will be helpful for large number of frames. However in STNCC, information of few neighbors are considered to estimate displacement more accurately. In light of this comment, we consider ideal case as proposed by the reviewer. We consider one frame and add seven different noises and generate seven different frames as pre-compressed data and repeat the same procedure for post-compresses data. We consider seven pairs of frames and estimate their strains individually and average the resulted strains as Fig.3. We also estimate strain field utilizing STNCC as shown in Fig.3(i). As it is clear STNCC has much better performance than averaged strain.

References

[1] M. T. Islam, A. Chaudhry, R. Righetti, A robust method to estimate the time constant of elastographic parameters, IEEE Transactions on Medical Imaging 38 (6) (2019) 1358–1370.

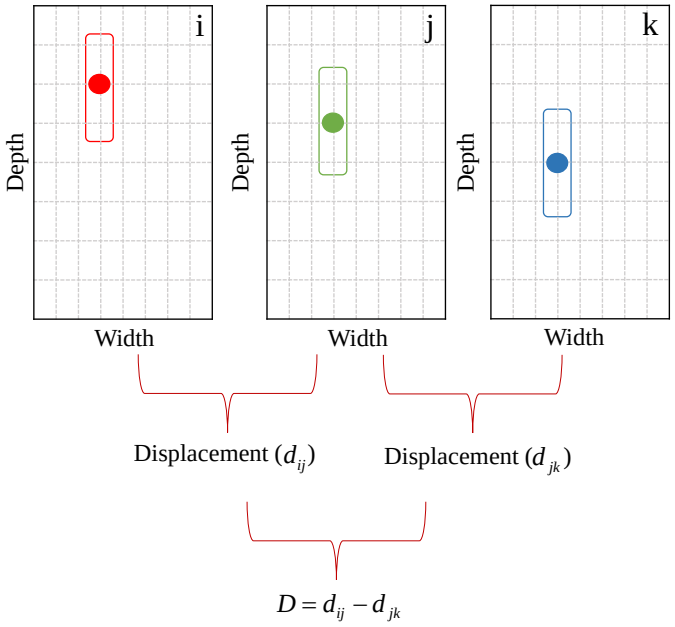
[2] M. Sridhar, M. F. Insana, Ultrasonic measurements of breast viscoelasticity, Medical physics 34 (12) (2007) 4757–4767.

[3] R. M. Sigrist, J. Liau, A. El Kaffas, M. C. Chammas, J. K. Willmann, Ultrasound elastography: review of techniques and clinical applications, Theranostics 7 (5) (2017) 1303.

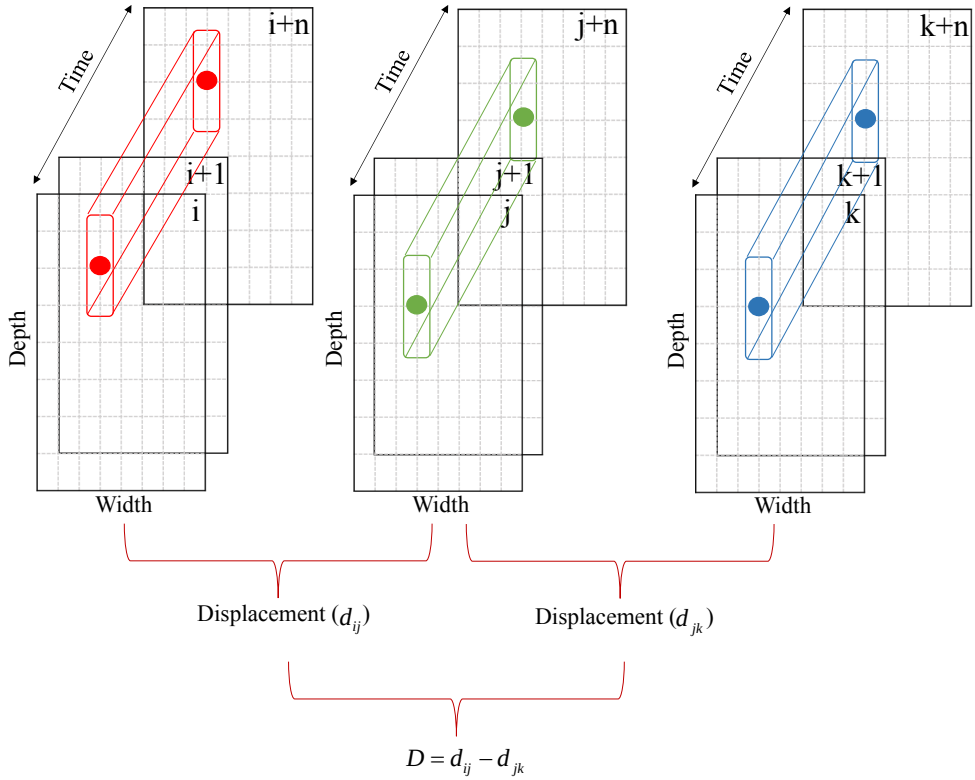
[4] K. Nightingale, M. S. Soo, R. Nightingale, G. Trahey, Acoustic radiation force impulse imaging: in vivo demonstration of clinical feasibility, Ultrasound in medicine & biology 28 (2) (2002) 227–235.

[5] E. Turgay, S. Salcudean, R. Rohling, Identifying the mechanical properties of tissue by ultrasound strain imaging, Ultrasound in medicine & biology 32 (2) (2006) 221–235.

*Morteza Mirzaei, Department of Electrical and Computer Engineering, Concordia University, EV10.113, 1455 Maisonneuve west, Montreal, H3G 1M8; Email, m_irzae@ece.concordia.ca

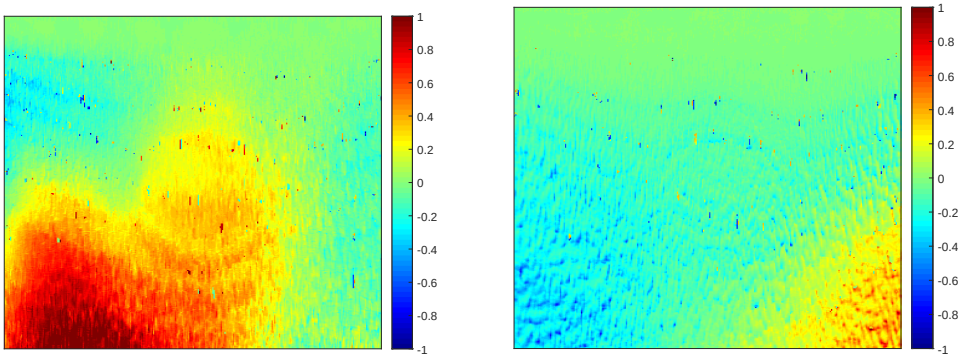


(a) Acceleration for NCC



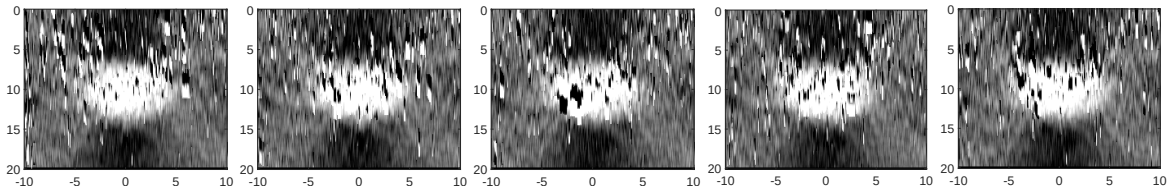
(b) Acceleration for STNCC

Figure 1: Difference of displacements in temporal domain that can be considered as acceleration of displacement and strain.

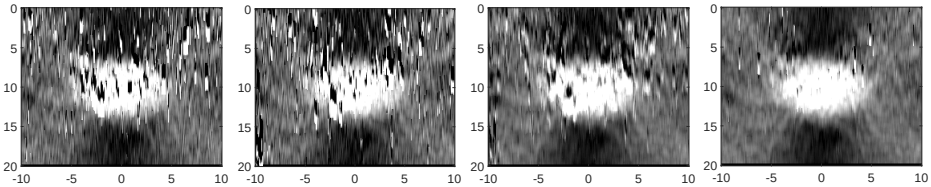


(a) Acceleration for NCC (D) (b) Acceleration for STNCC (D)

Figure 2: Difference of displacements in temporal domain that can be considered as acceleration of displacement.



(a) Frames 1 and 8 (b) Frames 2 and 9 (c) Frames 3 and 10 (d) Frames 4 and 11 (e) Frames 5 and 12



(f) Frames 6 and 13 (g) Frames 7 and 14 (h) Averaged 7 strain fields (i) STNCC

Figure 3: Strain images of the simulation phantom calculated using NCC and STNCC.