Bond thickness estimation for a composite structure using multiple inspection techniques

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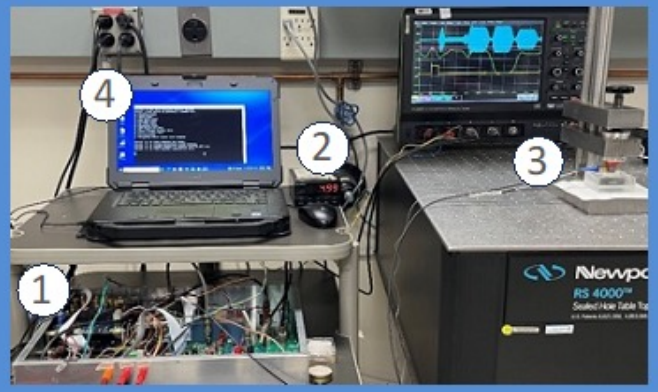
Outline

- Introduction/Motivation
- Synthetic test problem
- Fusion results
- Conclusions

Introduction

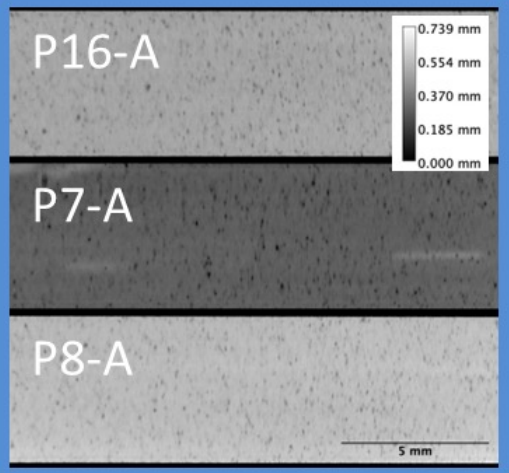
Phased Based Ultrasonic Measurement for Bond Strength



1 – Phase measurement circuit
2 – Load gauge
3 – Specimen under test
4 – Test control computer

Ultrasonic transmission (UT)

X-ray CT Wide Area Composite Bond Line Thickness Mapping



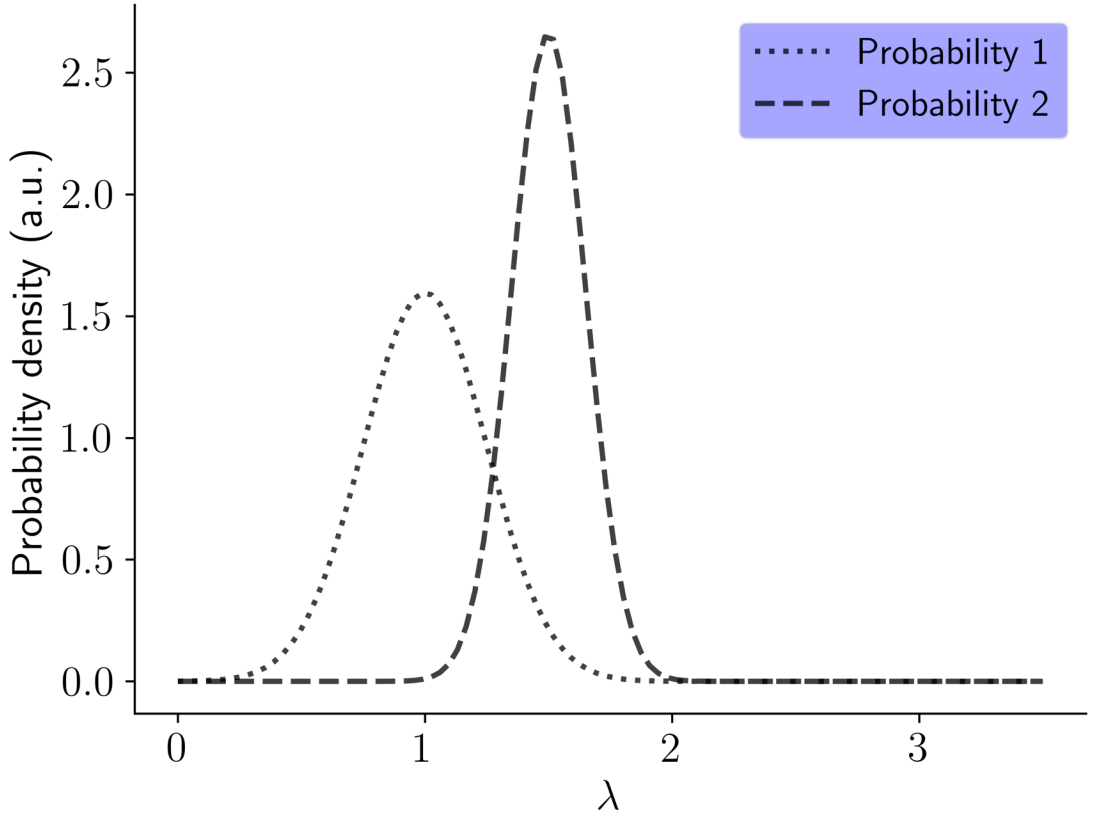
X-ray computed tomography (CT)

Bond thickness gauging using flash thermography

Thermography

Growing need to combine results from multiple inspections to characterize composites, additively manufactured materials, and more.

A General Estimation Problem[1,2]



Setup:

- Two independent sets of inspections conducted to quantify an unknown physical parameter λ

Outputs:

- Two valid probability distributions representing λ

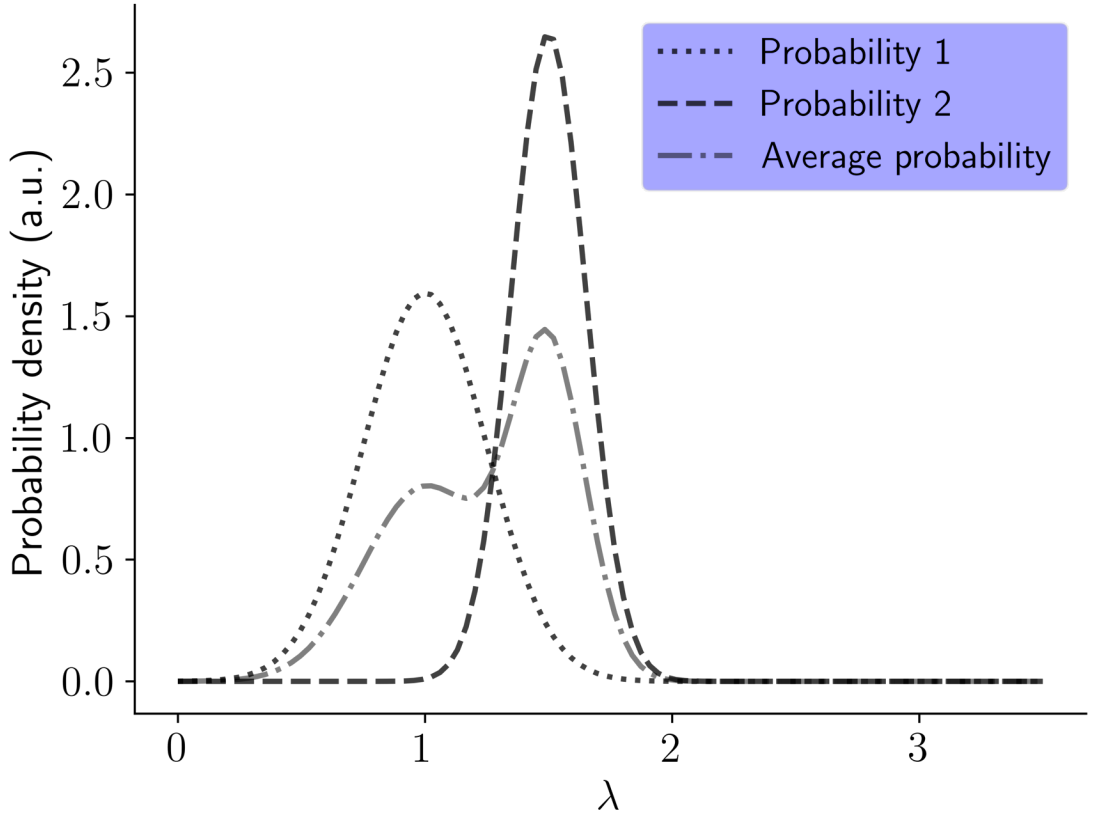
Question:

- How to combine the results into a single coherent probability distribution that represents the unknown parameter λ?

[1]Hill, T.P., Trans Amer Math Soc, **363**, 2011

[2]Hill, T.P. and Miller, J. Chaos, 21, 2011

Average of Probabilities?



Drawback 1:

- The variance is at least as large as the minimum variance of the given distributions

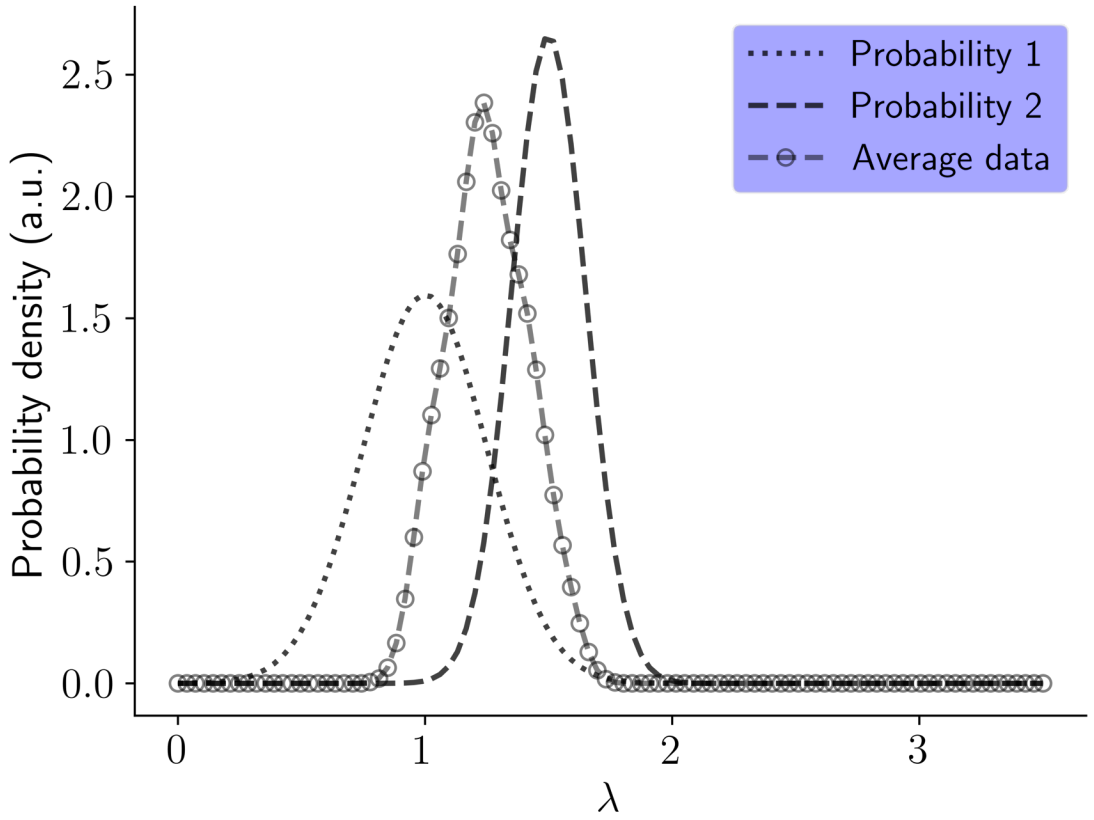
Drawback 2:

- The mean is equal to the average of the means no matter the ratio of variances of given distributions

Drawback 3:

- For normally distributed data, the average of probabilities tends to be multi-modal

Average of Data?



Drawback 1:

- The variance is never larger than the maximum variance of the given distributions

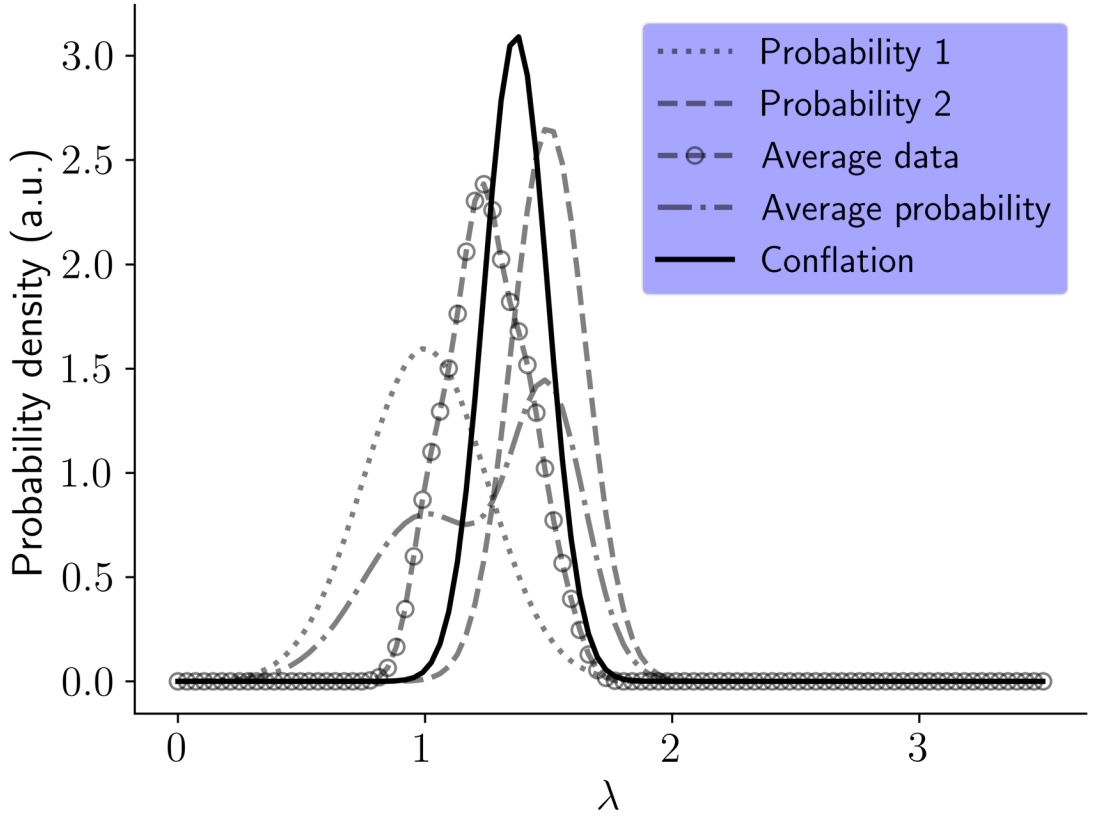
Drawback 2:

- The mean is equal to the average of the means no matter the ratio of variances of given distributions

Drawback 3:

- If the inspections are conducted using different methods, or the distributions are derived indirectly, then averaging the data does not make sense

Conflation of Probability distributions[1,2]



Advantage 1:

- Concentrated around the overlap of the input distributions

Advantage 2:

- The mean is closer to the mean of the given distribution with smaller variance.

Advantage 3:

- Conflation minimizes the loss of Shannon information

Advantage 4:

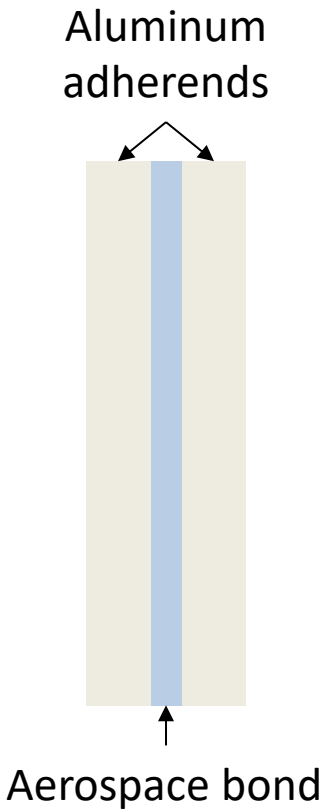
- Conflation of normal distributions is normal (same for most parametric families)

… and many more!

✓ $Q(P_1, P_2) = P(X_1, X_2 \mid X_1 = X_2)$

Synthetic Test Problem

Simulated specimen



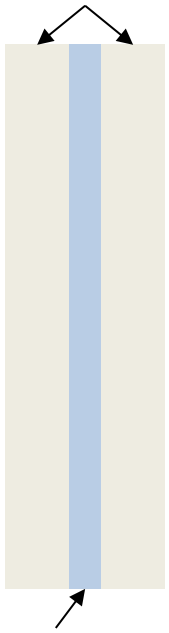
Problem assumptions:

- Bond thickness of 210 µm
- Total thickness 5 mm
- Known speed of sound that is constant in each layer
- Known thermal diffusivity that is constant in each layer
- 50 MHz UT pulse-echo inspection modeled with Gaussian pulse of width 40 µm and mixed boundary conditions
- Flash modeled by Dirac pulse at t=0 and insulating boundary conditions

Synthetic Test Problem

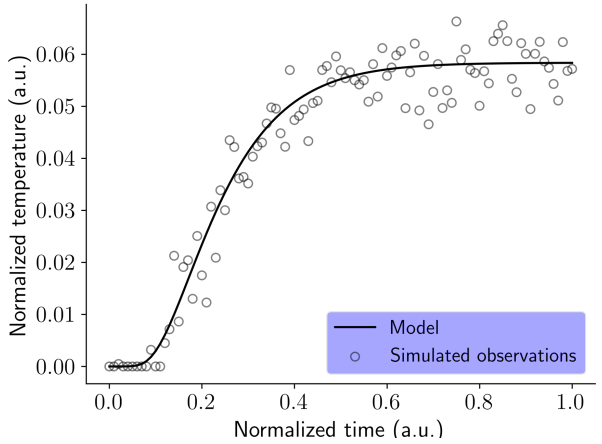
Simulated specimen

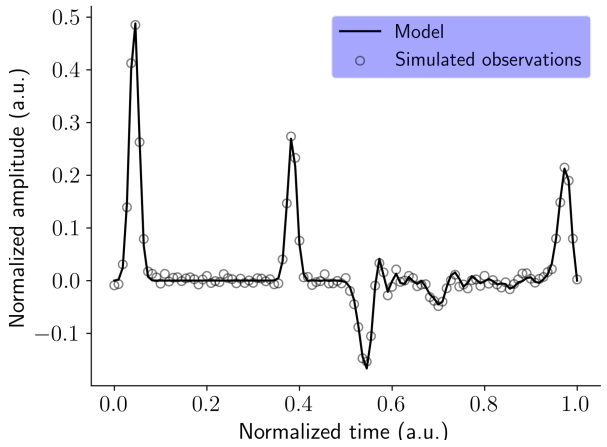
Aluminum adherends



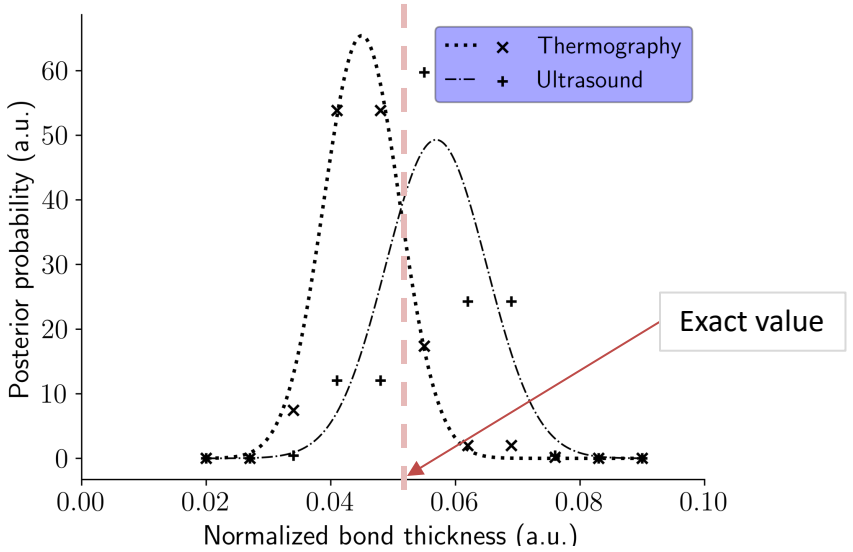
Bond

Simulated observations*



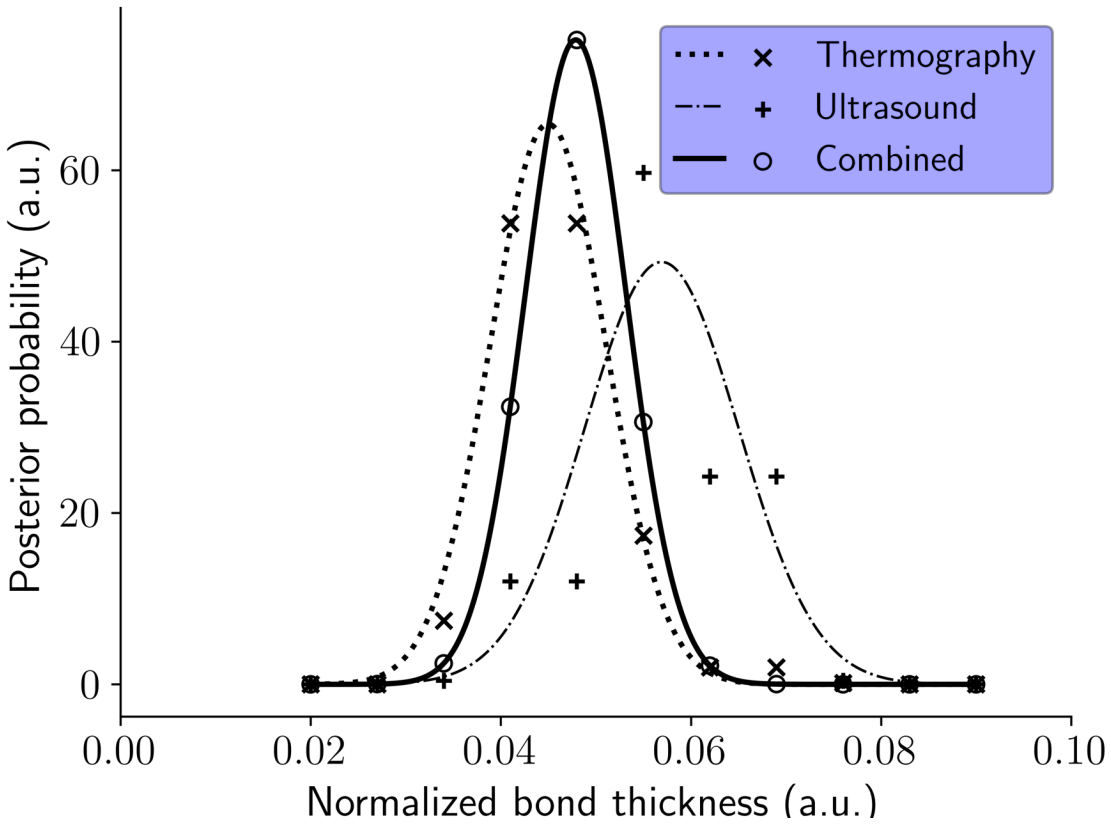


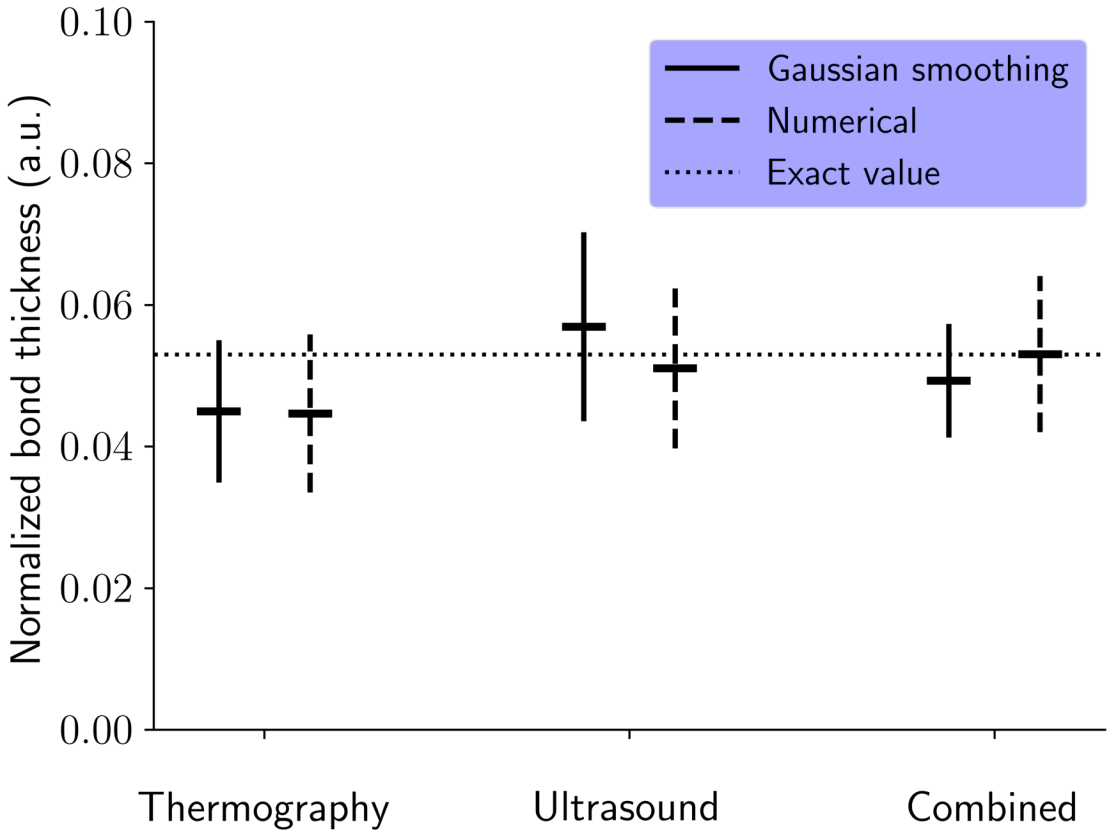
Bayesian posterior distributions



*Simulated measurements created using 1D numerical simulations of the thermography and UT inspections for the known bond thickness plus iid additive noise.

Results





The conflated posterior distribution improves on the constituent distributions in terms of precision and accuracy.

Conclusions

- The conflation of posterior distributions is a valid means of consolidating probability distributions derived from NDE inspections (NDE + Uncertainty Quantification)
- Conflation can be applied to combine inspections of the same or different modalities.
- Testing the approach on experimental data is an important next step.

Acknowledgements

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