Real-Time Ultrasonic Thermometry Based on the Change in Backscattered Energy (CBE)

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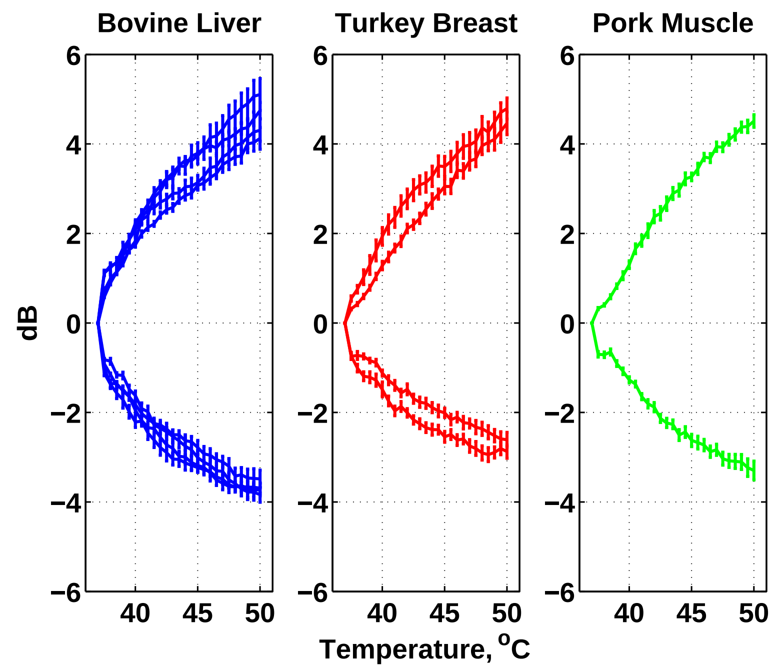
CBE Thermal Sensitivity

Ultrasonic backscattered energy increases or decreases with temperature depending on scatterer type

- Theoretical analyses
- Simulation of scatterer populations
- Measurements in 1D, 2D and 3D
- Monotonic to >60°C



Change in backscattered energy comes from a pixel-by-pixel ratio of images at different temperatures

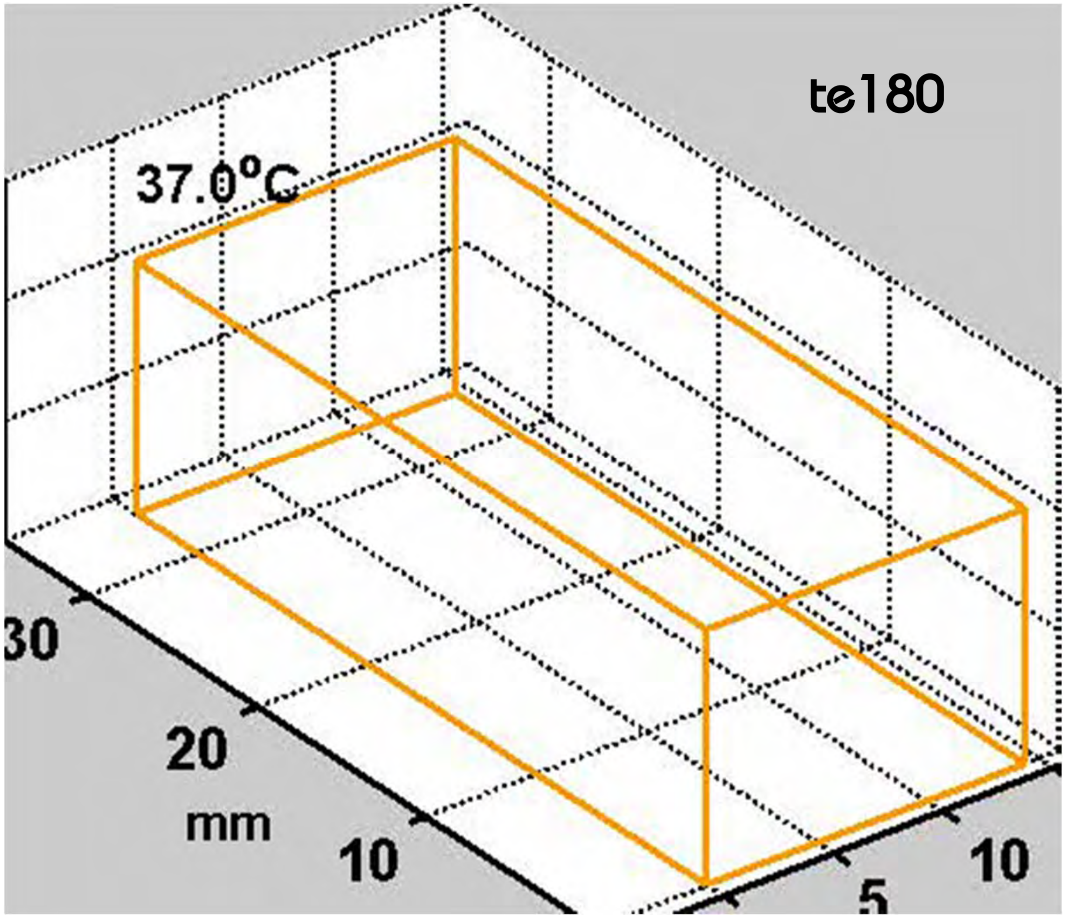
Objective

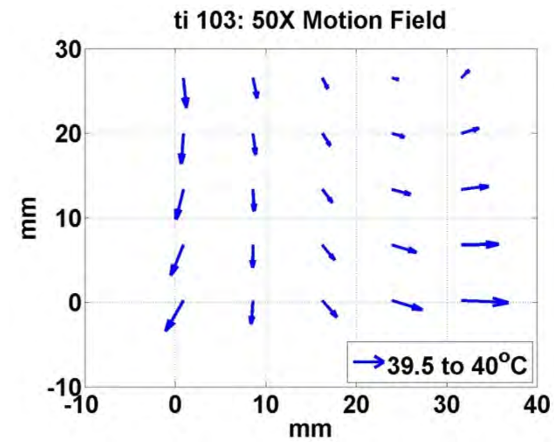
Produce CBE-based temperature images within the image-acquisition interval needed to assess thermal therapy with 1°C accuracy

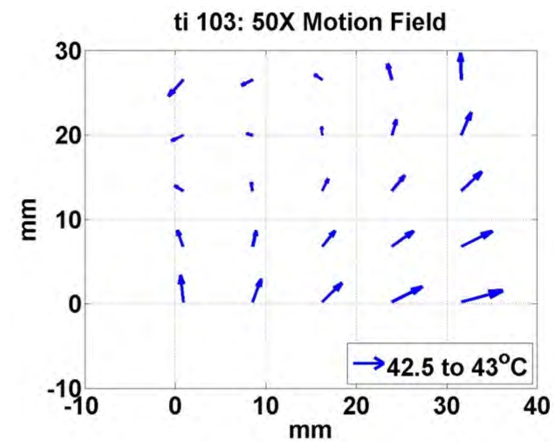
Motion Compensation

- Limits real-time CBE temperature imaging
- Requires aligning images for a pixel-by-pixel determination of CBE

3D Non-Rigid Motion Compensation





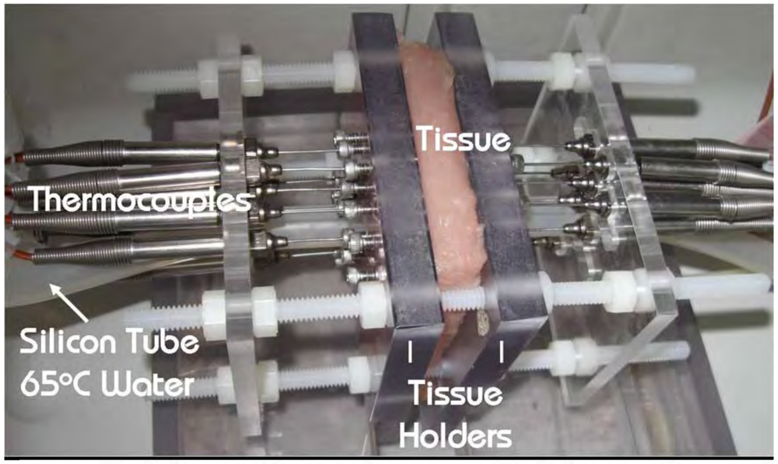


- Estimated using conventional optimization
- Comparable to motion seen in 2D
- Arrow lengths are 5X actual motion field

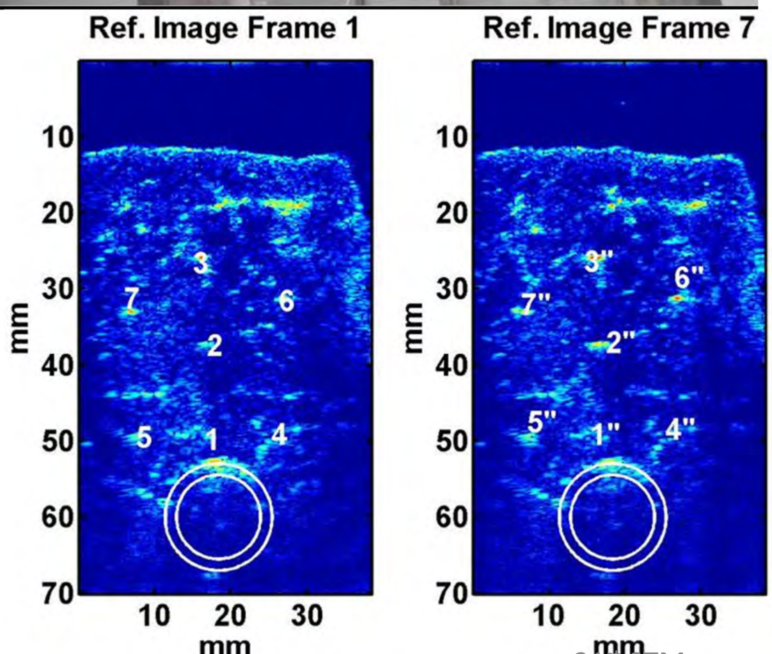
For real-time operation we use
1) Rigid Motion in 2D
2) Over sub-regions

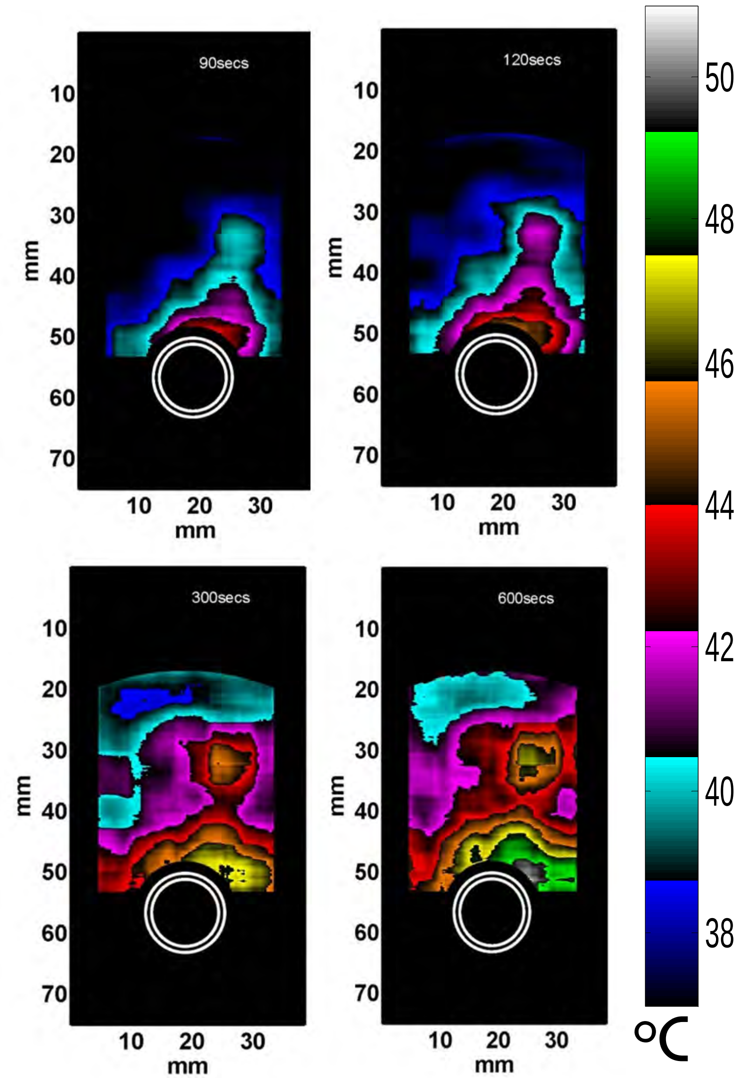
Temperature Imaging with CBE during Non-uniform Heating

Fixture



Thermo-couple locations





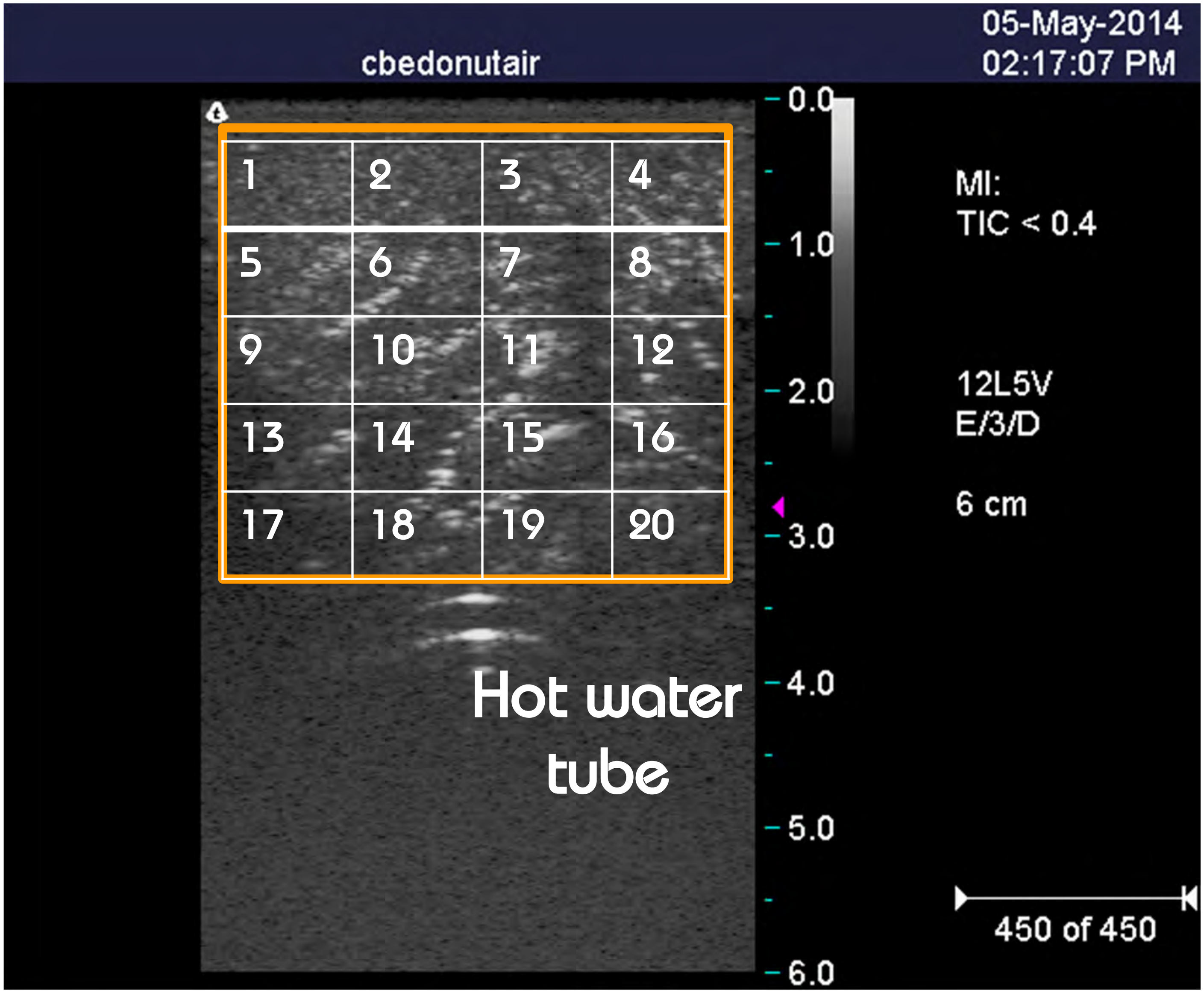
~1 °C accuracy

2D Motion Compensation

Region: Orange

Sub-regions: White

Image pixels spacing, µm
- 32 axial
- 300 lateral



CPU & GPU Times for Image Interpolation

To track motion, pixel spacing must be interpolated

Interpolated pixel spacing tested

- ➢ 8 μm axially (4x)
- ➢ 20 μm laterally (16x)

On a CUSTOM WORKSTATION @ *Lickenbrock Technologies, St. Louis*

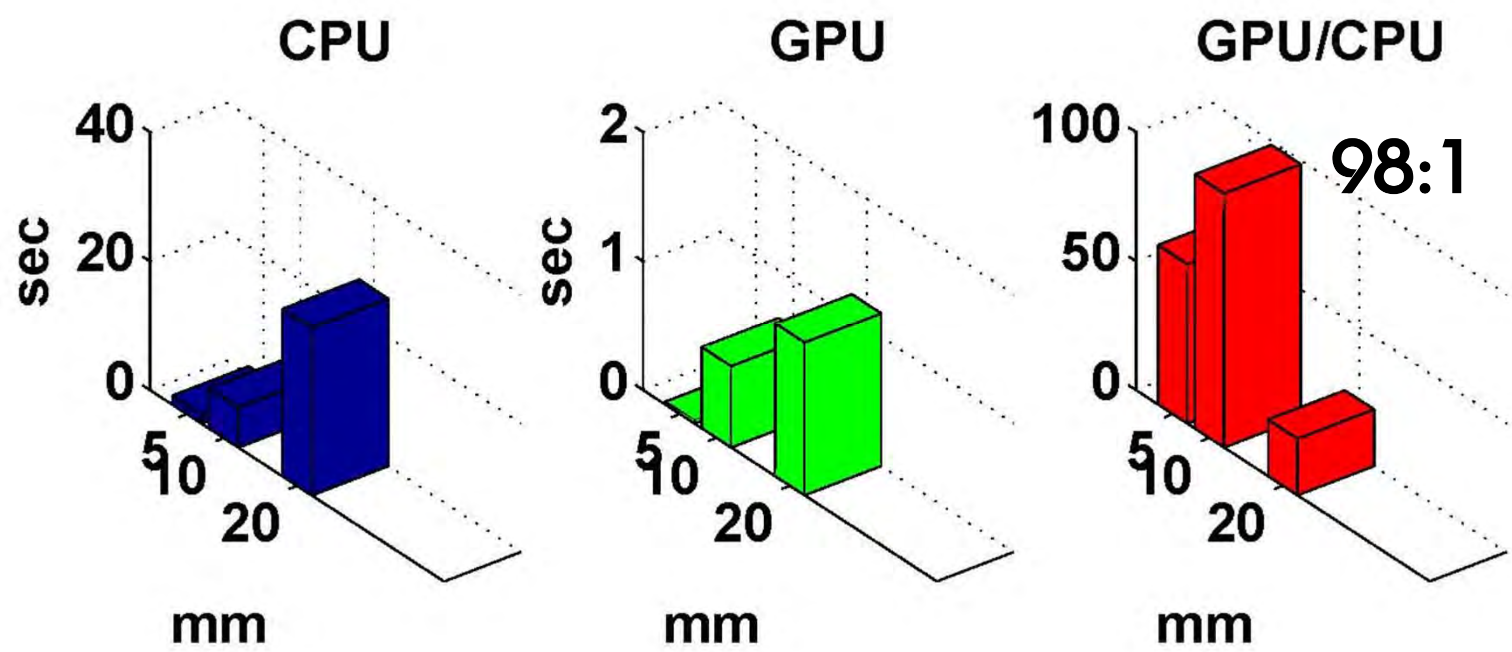
- ASUS P5Q-EM mainboard
- CPU: Intel Core 2 Quad Q9300, 2.5 GHz processor & 8 GB RAM
- GPU: NVidia GTX260 with 896 Mbytes Video RAM.

GPU/CPU was 9:1

(0.7 sec vs 6.3 sec)

For a 1000 x 112 image interpolated to 7M pixels

CPU & GPU Times for Rigid 2D Motion Compensation



Using the CUSTOM WORKSTATON

GPU improvement over CPU compensation

- Depended on region size
- 98 times faster for 10x10 mm regions

Temperature-Imaging Experiment

td707

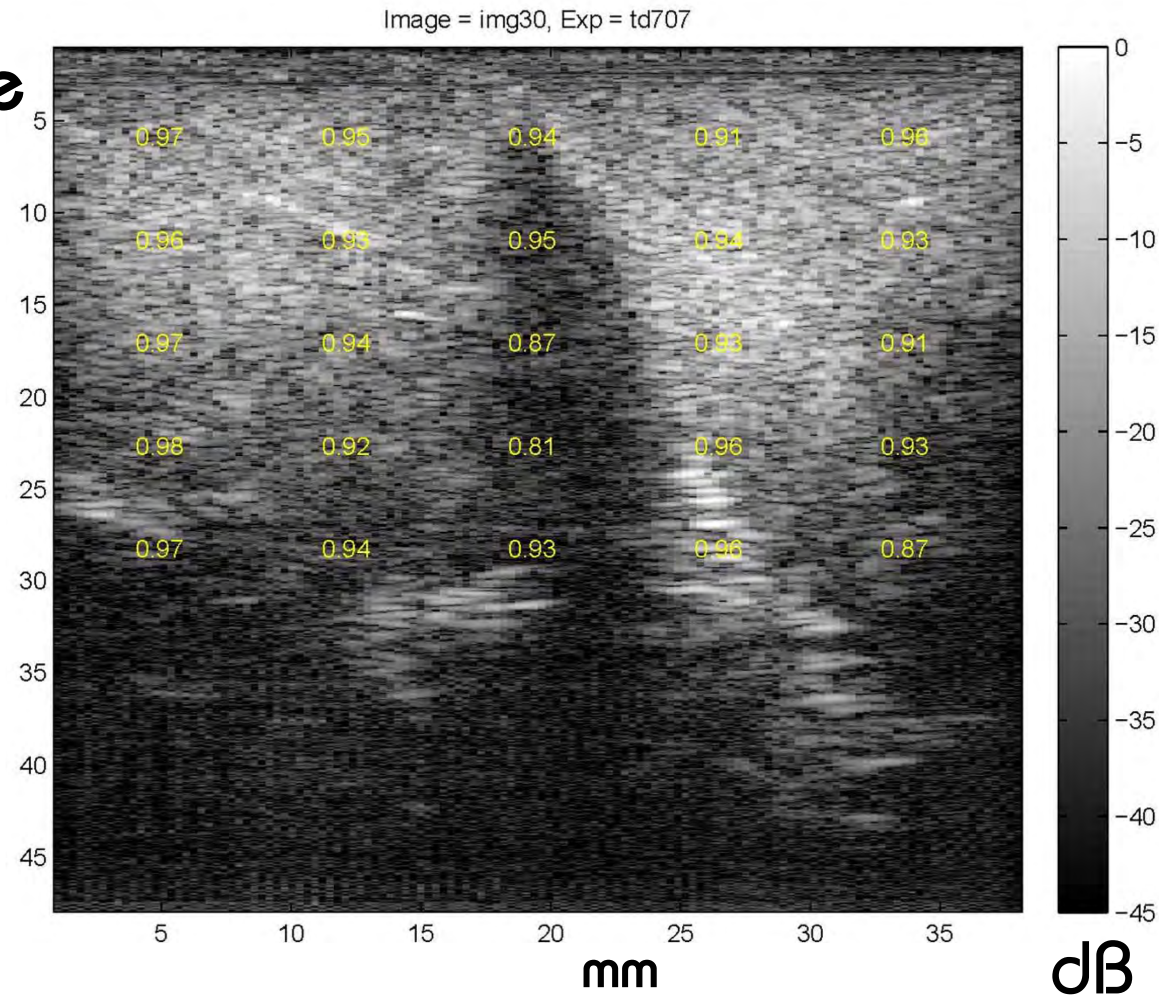
2D Interpolation & Motion Compensation

HP DV6: Quad core 2.5GHz

25 (5x5) sub-regions

Time ~ 12 sec

With GPU < 1sec

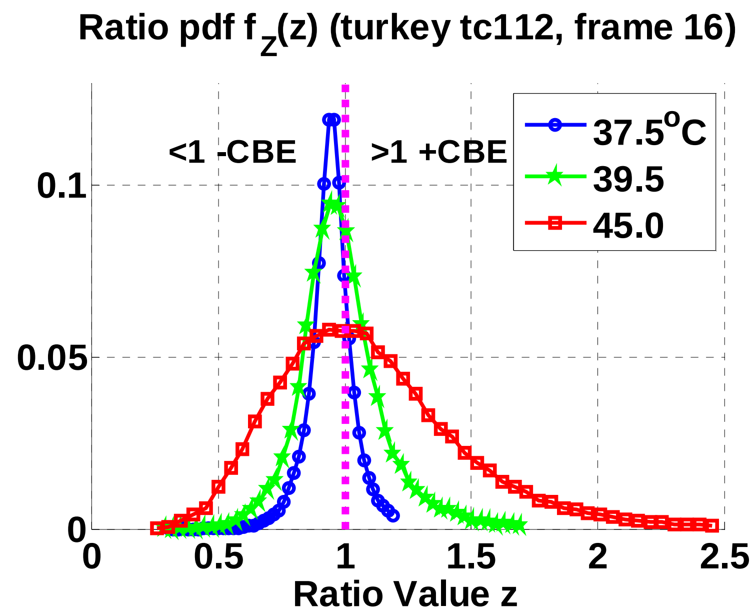


Framework for CBE Computation

- CBE from the ratio of two random variables

$$z = \frac{y_T}{y_0}$$

where y_T and y_0 represent envelope images at temperature T and T_0.



- The distribution of z comes from the joint distribution of y_T and y_0

$$f_Z(z) = \int_{-\infty}^{\infty} |y_0| f_{y_0 y_T}(y_0, y_0 z) dy_0$$

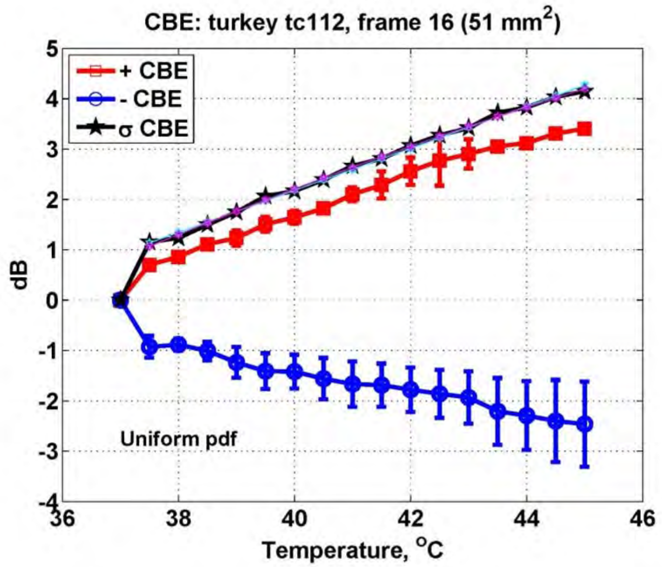
which is a temperature dependent probability density function (pdf)

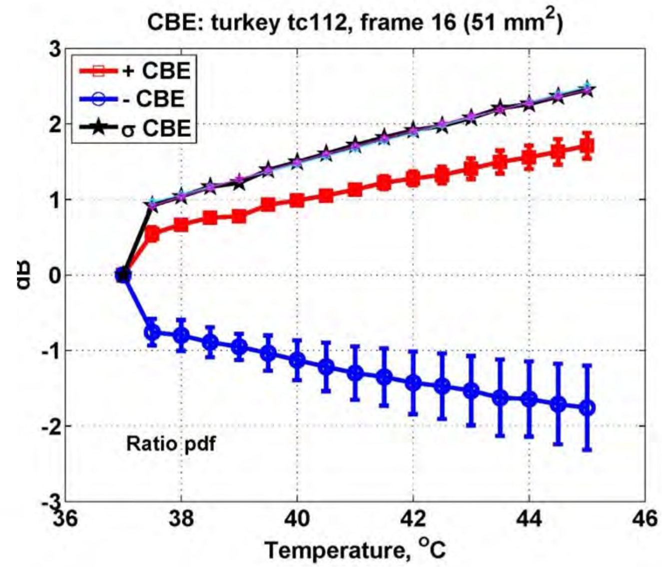
- PCBE (+CBE) & NCBE (-CBE) are statistics of the ratio

$$PCBE = \frac{\int_1^{\infty} z f_Z(z) dz}{\int_1^{\infty} f_Z(z) dz} \qquad NCBE = \frac{\int_0^{1} z f_Z(z) dz}{\int_0^{1} f_Z(z) dz}$$

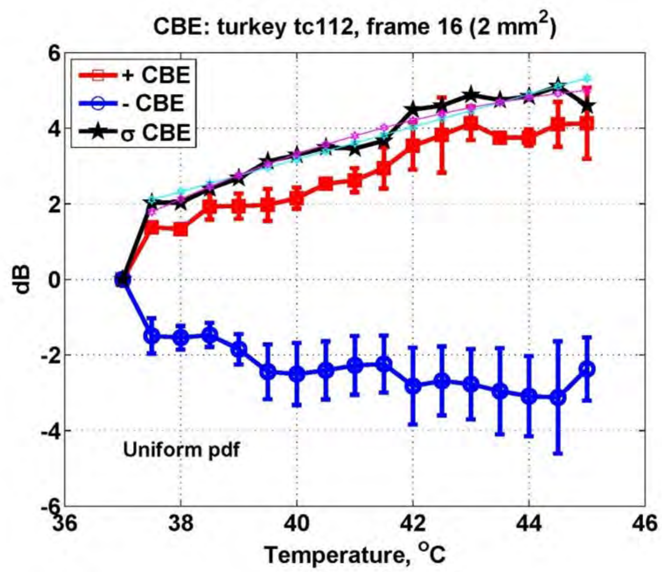
Measured CBE with Region Size

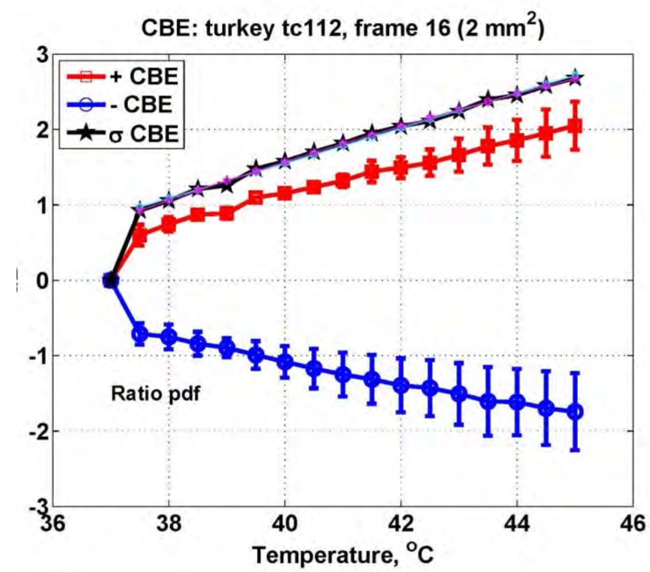
For a "large" region (51 mm^2), the effect of the ratio pdf is small





For a region 25 x smaller (2 mm^2), the ratio pdf effect in linearizing CBE is significant





Summary & Conclusions

- CUSTOM WORKSTATION Tests of GPU vs CPU Times
  - Interpolation time was reduced by almost an order of magnitude (6.3 to 0.7s) with the GPU
  - Motion Compensation was reduced by up to 2 orders of magnitude depending on sub-region size (6.21 to 0.63s)
- Experiments with a CPU similar to WORKSTATION
  - Interpolation and motion-compensation in 12s
  - Results suggest CBE TIs in <1 sec with current GPU cards
- We expect to maintain 1°C accuracy & even improve spatial resolution in TIs using CBE corrected with image-ratio pdfs, in real time using GPU processing