A novel array processing method for precise depth detection of ultrasound point scatter

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Background

- Point source aberrations have been studied extensively in astronomy, optical microscopy, etc.
- Information that increases depth resolution can be extracted.
Optical System

Multi-Plane Imaging

- Fluorescent particles with a diameter of 200 nm mounted on precision translation stage.

- Three simultaneous images are acquired for each position of the translation stage that is then moved to the next position.
Normalized Image Sharpness

Extracted from a small window including only one particle by:

\[ S = \frac{\sum_{k=1}^{q} (n_k^2 - n_k)}{\left(\sum_{k=1}^{q} n_k\right)^2} \]

and combined with Maximum Likelihood Estimation (MLE) results in...
**Accuracy**

Ultrasound simulation

- Transducer definition
- Moving point target
- Ultrasound transmission
- Multiple receive foci
- Noise addition


Transmit & receive processing

- Transmit focus can be set only once during each acquisition
- Offline beamforming with multiple foci in receive
Ultrasound simulation

- Beamformed responses of a moving point target.
- Three different receive foci (with 2 mm distance).
- Dimensions are 14x20 mm$^2$ for each image plane.
Normalized Ultrasound Sharpness

Transmit focus at 30 mm

Transmit focus at 50 mm

- Extracted by signal amplitudes:
  \[ S = \frac{\sum_{k=1}^{q} A_k^4}{\left(\sum_{k=1}^{q} A_k^2\right)^2} \]
Normalized Sharpness

Biological Microscopy

Ultrasound

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Maximum Likelihood Estimation

- Repetitive measurements: due to noise sharpness curves are not identical
- General curve shape maintained as in optics; similar PDF selected

PDF model:

\[ P(s_j | z) = \frac{e^{S_j^2} S_j^{\alpha-1}(z) \beta^{-\alpha}}{\Gamma(\alpha)} \], \quad \alpha = \frac{S_j^2(z)}{\sigma_j^2} \quad \text{and} \quad \beta = \frac{\sigma_j^2}{S_j^2(z)} \]
Accuracy with shorter transmit focus

\[ \lambda = 220 \mu m \]
Accuracy with longer transmit focus
Conclusion

• An ultrasound method originating from biological microscopy has been presented.

• Three or more simultaneous sharpness values can be extracted for each depth position of a moving target.

• Image sharpness based algorithm may reach down to $\lambda/6$ axial resolution.

• Further investigation and experimental validation are needed before being suitable for real-time applications.
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