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# Upper Bound of Accuracy for Self-Calibration of a 3D Ultrasound Tomography System without Ground Truth

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A Newton's method based self-calibration was presented in previous work for a 3D Ultrasound Tomography System (USCT). The method sequentially calibrates a complex USCT system with 2041 transducers based on time-of-flight (TOF) measurements. A direct evaluation of the calibration result was not possible due to unknown ground truth. In this work we present a method to estimate the upper boundary for the calibration accuracy.

## (2) Material and Methods

The overall calibration accuracy is given by the sum of residuals $r$ of the equation systems in $N$ calibration steps and the estimated TOF error $|\Delta b|$ weighted by the condition numbers $\kappa_i$, see Fig.: $\epsilon = |\Delta b| \cdot c \cdot \sum_i^N \kappa_i + \sum_i^N r_i$. For a nonlinear equation system $\kappa_i$ was estimated in each calibration step by investigating the error propagation, describing its sensitivity to an error in the TOF detection. For a nonlinear equation system $f$ at a point $x$, $\kappa$ can be computed with: $\kappa = ||J(x||/(||f(x)|| \cdot ||x||)$. We computed $\kappa_{i,max}$ for $N = 3$ calibration steps with 500 iterations at $x$ equal to the default state of USCT with small changes $\delta x$.

## (3) Results

The TOF error $|\Delta b|$ was estimated for 10 consecutive USCT measurements of water only. Due to identical positions of the transducers and temperature monitoring, the detected deviation is only caused by errors in the TOF detection, characteristic deviation of individual transducers and system jitter. The maximum value of $|\Delta b|$ is given by the width of the detection window centered on the expected TOF using prior knowledge. We obtained $|\Delta b|$ of 0.11 µs at 30℃. With sum of $\sum_i^N \kappa_{i,max} = 1.64$ and sum of residuals in the order of $10^{-7}$ m the upper bound of the calibration error is 1.2 mm and the estimated upper bound of the mean error is ϵ = 0.14 mm.

## (4) Discussion and Conclusion

For a given solver and measurement setup $\kappa$ can be reduced by increasing the number of independent measurements, in our case by adding TOF measurements, i.e. increasing the number of included A-scans. On the other hand, $|\Delta b|$ can be reduced by excluding A-scans with low SNR. The presented method enables finding the optimal tradeoff between reduction of $\kappa$ and $|\Delta b|$ for an optimal upper bound for the calibration error smaller than 1/4 of the wavelength of 0.15 mm.

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