Depth Control Using Acoustic Waves During Laser Ablation

University of Basel
Department of Biomedical Engineering

Carlo Seppi[1], Antal Horvath[1], Hervé Nguendon[2], Azhar Zam[2] and Philippe C. Cattin[1]

[1]CIAN, [2]BLOG – Department of Biomedical Engineering, University of Basel

Project MIRACLE
Planning and Navigation
CIAN

Motivation

Goal: We build a robotic endoscope to perform minimal invasive bone surgery with a laser light on the tip of the endoscope:

- cut through bones and muscle
- reduce trauma and improve recovery time

My Task: Use acoustic waves generated by the ablation of the medium (e.g. bone) from the laser light [1] to

- control the depth of the cut
- reveal the structure of the bone
- get a real-time feedback

Method

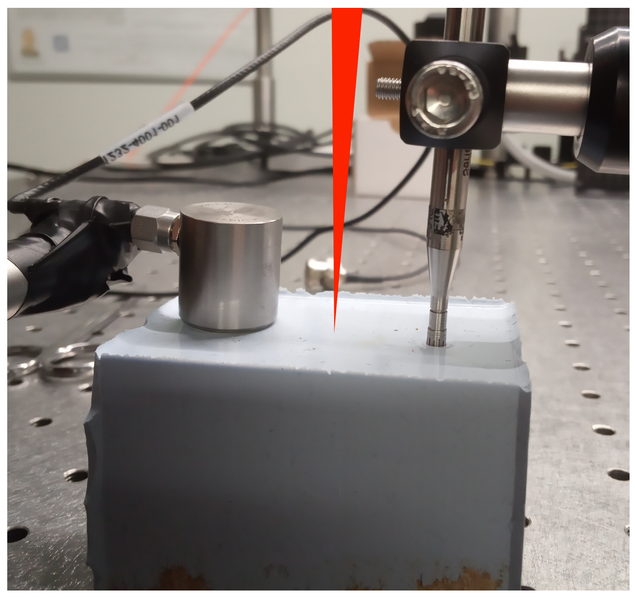
Forward Problem: Apply Fourier transformation of the *Wave Equation* yields the *Helmholtz Equation* in the frequency domain:

$$\begin{cases} -\omega^2 y(x) - \nabla \cdot (u(x)\nabla y(x)) = f(x), & \text{in} \quad \Omega, \\ \dfrac{\partial y}{\partial n} - iky = 0, & \text{in} \quad \partial\Omega, \end{cases} \tag{1}$$

- $u(x) > 0$ square medium
- $y(x)$ wave at location x
- $f(x)$ source function Term
- *Sommerfeld Boundary:* unbounded domain

Inverse Problem: The acoustic waves generated by the laser ablating the medium will be used to reconstruct the structure of the bone and find depth of the laser-cut [2].

Current Work



Nd:YAG Laser

- 532 nm

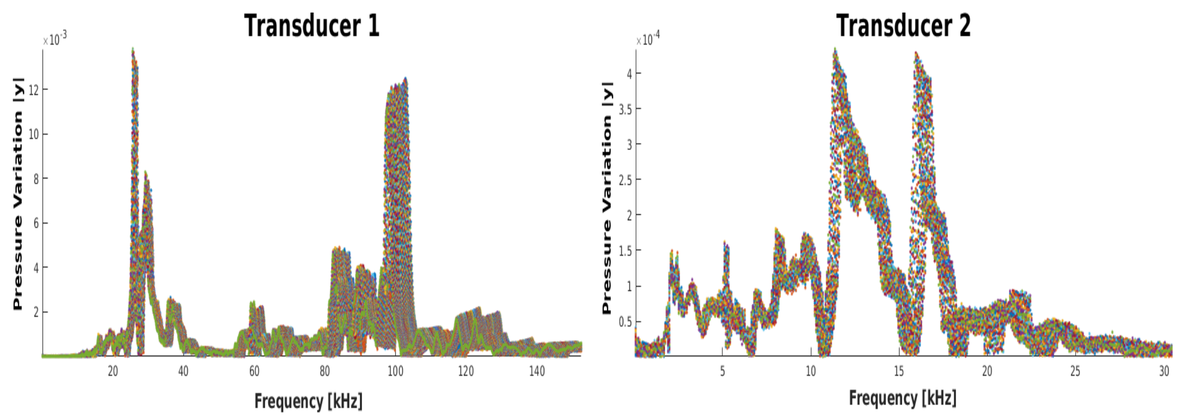
Transducer 1:

- ∅ 33 mm
- 10 kHz – 900 kHz

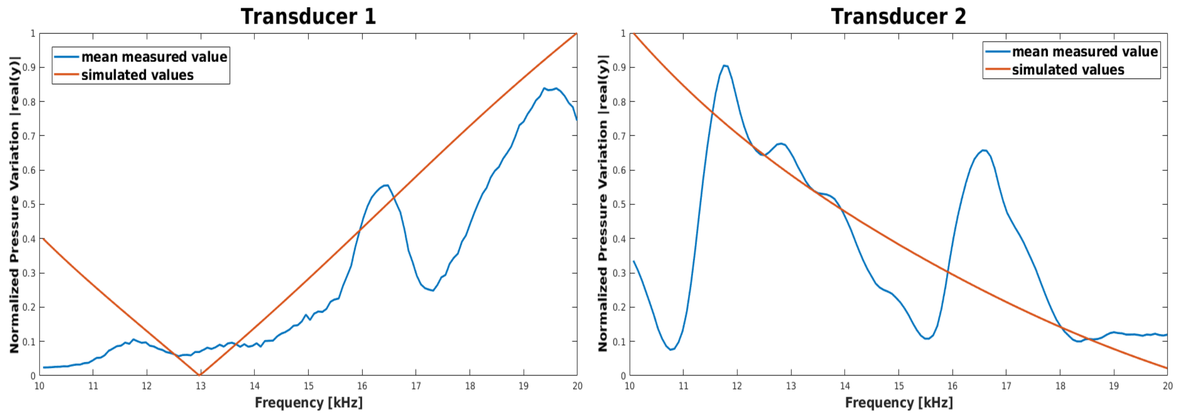
Transducer 2:

- ∅ 19 mm
- 7 Hz – 140 kHz

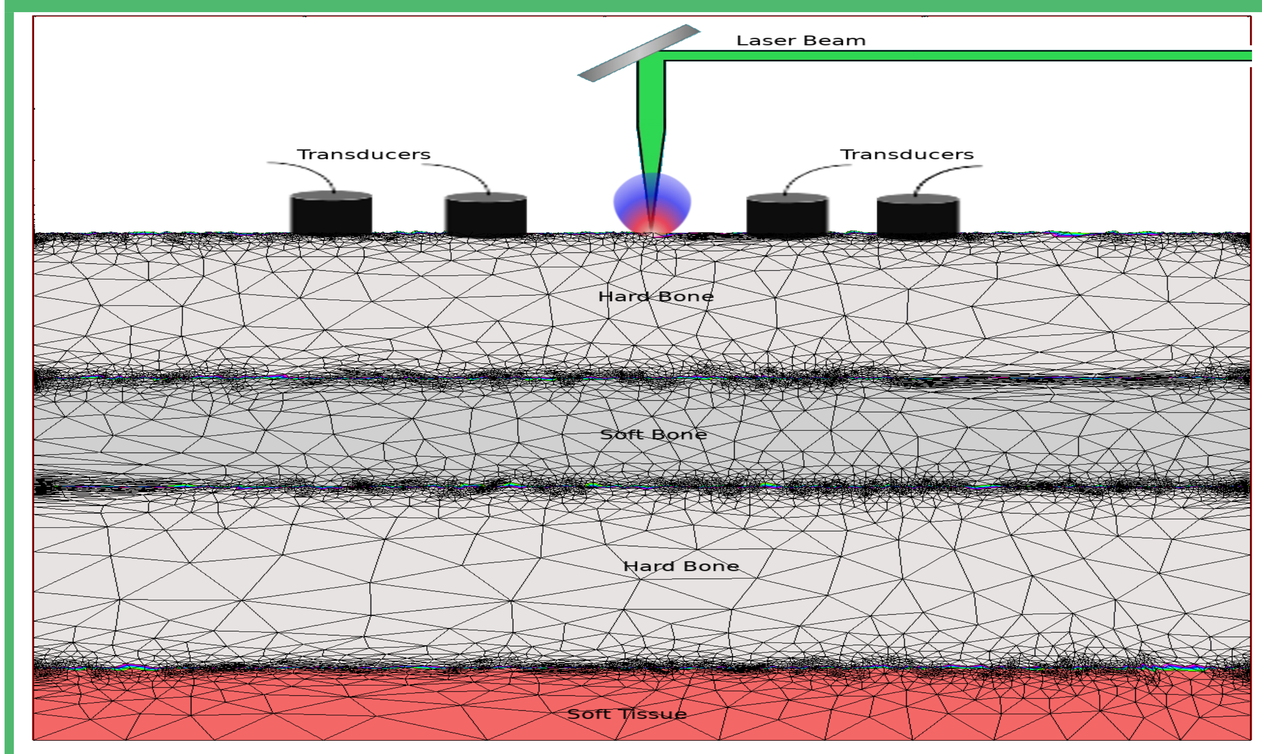
Fourier Transformation of Measured Signal



Measurement vs. Simulation



Challenges



Challenges:

- How do we find the ground truth?
- 3D simulations are very time intensive.
- Limited number of Transducers.
- Unknown form of the Source.

References

[1] Hervé K. Nguendon et al., "Comparison of acoustic shock waves generated by micro and nanosecond lasers for a smart laser surgery system" 2017.

[2] U. Nahum, A. Zam, P. C. Cattin "Bone reconstruction and depth control during laser ablation" 2017.

carlo.seppi@unibas.ch

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