Depth Control Using Acoustic Waves During Laser Ablation

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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 cut depth
- reconstruct the structure of the bone
- real-time feedback

Method

Forward Problem: We apply Fourier transformation of the **Wave Equation** resulting in the **Helmholtz Equation** [2] in the frequency domain.

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

- $u(x) > 0$ 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. We find the structure of the bone by minimizing

$$\arg\min_{u} ||Py(u) - y^{obs}||^2_{L^2} + \alpha R(u). \tag{2}$$

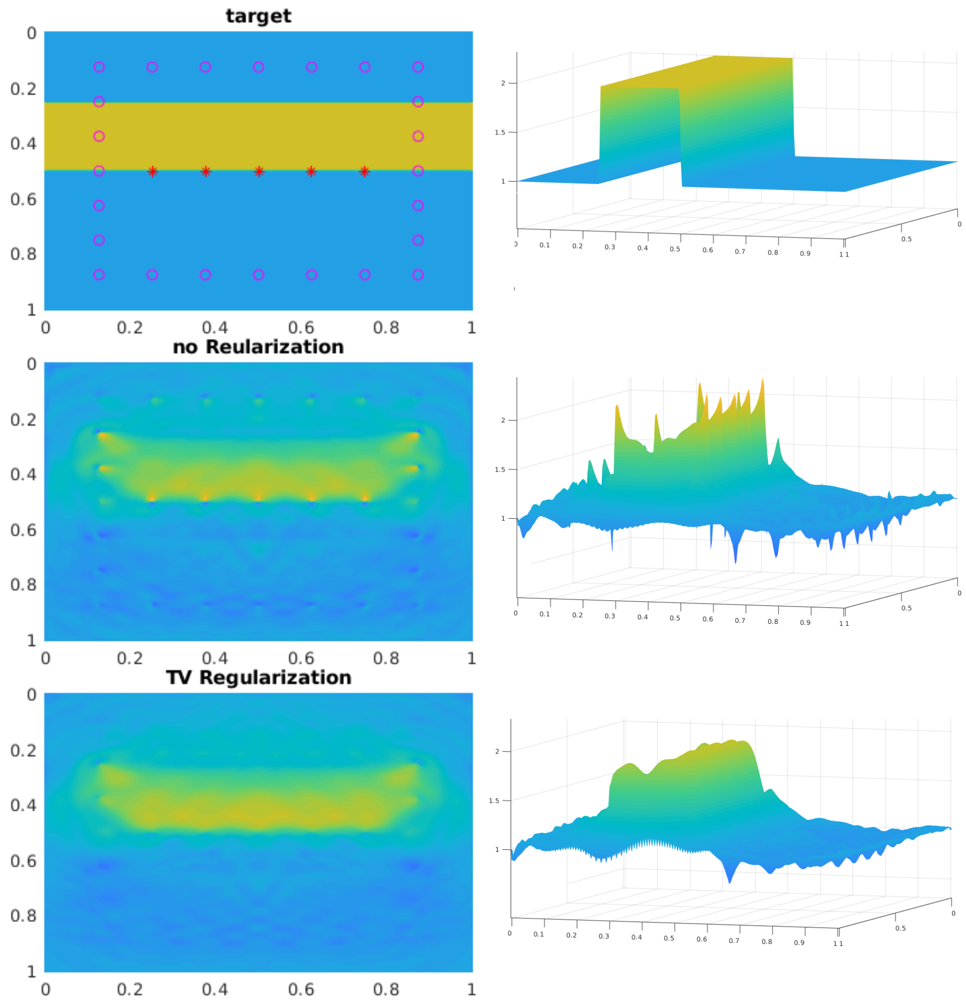
- y^{obs} observation of acoustic waves with microphones
- P projection at microphones position
- medium $u(x)$ is unknown
- $R(u)$ regularization term
- use **Inexact Newton** to solve the *iverse problem*

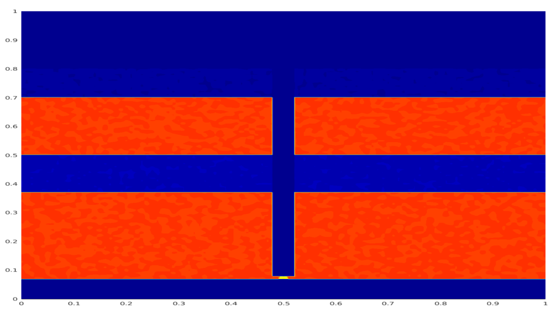
We choose the **TV-Regularization** [2]

$$R(u) = \int_\Omega \sqrt{|\nabla u|^2 + \varepsilon^2}\, dx\,,\ \varepsilon \neq 0,$$

to get a smooth reconstruction, without turbulence at the microphones and source position.

Current Work



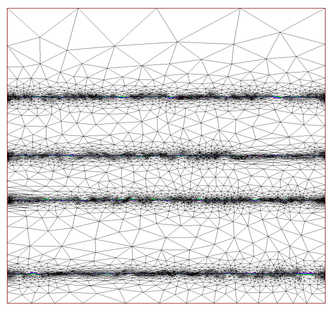


Adaptive Eigenspace method [2] used on simulated 2D data to reconstruct the

- structure of the bone
- depth of the cut (accuracy $0.4mm$)

Apply Inexact-Newton on Finite-Element [2] using Freefem++[5] to get an Adaptive mesh

⇐ given medium $u(x)$
adaptive mesh ⇒



Future Work

- apply on complex bone structure
- find the optimal number and position of the microphones [4]
- extend the simulation from 2D into 3D space
- apply on real data measurement

References

[1] Hervé K. Nguendon et al., "Comparison of acoustic shock waves generated by micro and nanosecond lasers for a smart laser surgery system" *Advanced Biomedical and Clinical Diagnostic and Surgical Guidance Systems XVI* 2017.

[2] M. Grote, M. Kray and U. Nahum "Adaptive eigenspace method for inverse scattering problems in the frequency domain" 2017.

[3] Kanawade Rajesh et al., "Qualitative tissue differentiation by analysing the intensity ratios of atomic emission lines using laser induced breakdown spectroscopy (LIBS)" *Journal of Biophotonics* 2015.

[4] E. Haber, L. Horesh and L. Tenorio "Numerical methods for experimental design of large-scale linear ill-posed" *Inverse Problems*, 2008.

[5] www.freefem.org

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