Spatial Analysis for SRμCT Segmentation

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ARTICLE INFO

ABSTRACT

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Motivation

- Hvad er det vi undersøger? - Overordnet: Imlantanter i knogler - Vil gerne kunne analysere og evaluere kvaliteten af "growth" omkring implantatet for at kunne vurdere den underlæggende sundhed og success af operationen - Vil gerne kunne afkorte tiden fra operation til analyse til evaluering, samtidigt med at kvaliteten af data er stabil til at der er højt evidensgrundlag - kunne sige noget om knoglekvaliteten og kompositionen (tæthed, radius, ...) - kontakt til implantat: dækket af knogle, blod (forbundet til blodnetværk)

- Hvilke problemer indebærer det som skal løses? - Segmentation is hard and time-consuming to do on this type of data. - contains noise that is hard to avoid from data acquisition - often segmentation is done manually, so being able to automate

this data is of great value for the field. - Want to avoid using deep learning methods, but keep full transparency - Simpler mathematical methods can be implemented efficiently and consistently

- Hvordan vil vi bære os ad med at løse problemerne? - Det er en forudsætning at vi tydeligt kan observere hvad der sker i bone-to-implant interfacet - Den utrolig høje opløsning og kvaliteten af billeder fra SR-micro-CT vil give adgang til analyse og segmentering med høj nøjagtighed. - Using the geometrical distributions and domain specific knowledge means that we know what to expect from the segmentation around all regions.

Data

The physical samples

The physical samples are prepared for SRμCT scanning by cutting out a portion of a larger 12mm cylindrical sample. [Aleksandar: Better to give a brief chronological tour of how the sample has been handled? Time scale also matters to men-

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[1]This is author footnote for second author.

tion in regards to growth.] The cut samples are 6.5mm cubes [Aleksandar: more accurate measures?]. This contains the titanium dental implant (Astra Tech OsseoSpeed, ST Molndal, Sweden), which is 3.5mm in diameter and 8mm long. Along its length the lower 5.5mm has larger threads and is attached to recipient bone. The upper 2.5mm has smaller threads and is where newly formed bone is to be assessed. Sorrounding the bone and implant contact-region are cavities containing resin, air, blood vessels and other fibrous tissue. This is shown in figure 1.

Each material has a different density and thus absorption. The titanium implant has higher absorption than bone. Bone material then has higher absorption than its sorrounding tissue, vessels, air and resin.

Data acquisition

It can be difficult to study and evaluate the bone structure and blood network without destroying or manipulating the sample. X-ray computed tomography is a widely used tool for non-intrusive medical imaging. By exposing a subject to X-rays, we can map the linear attentuation coffecient of the passing rays. Each ray is attenuated relatively to the density and composition of the material it passes. By rotating either the scanner or the sample we can get a full 3D image representation of the inner structure of the sample. Each volumetric pixel (voxel) then represents the X-ray attenuation at its spatial position. We can therefore reliably use X-rays to internally characterise samples in a non-intrusive and non-destructive manner. Regular CT-scans can provide spatial resolutions on the order of millimetre scale.[Aleksandar: ref] The more modern micro computed tomography (μCT) can provide much higher spatial resolution on the micrometre scale.[Aleksandar: ref] Both setups utilize poly-energetic beams, which can cause artifacts around high density regions. This effect is called beam-hardening[Aleksandar: ref], and occurs when rays with lower energy are attenuated more frequently. This offsets the local contrast, by overestimating the attenuation, leaving lighter spots on the image. Many other types of artifacts will also occur in these common scanners, but most is taken into account by calibration using phantoms and pre-hardening the beam before it reaches the sample. Due to its common usage, much software also exists to correct for noise and smaller imperfections during reconstruction[Aleksandar: ref].

This work focuses on data acquired by Synchrotron Radiation micro-CT (SRμCT). For this imaging technique, electrons are accelerated to ultra-relativistic speeds in trajectories directed by strong magnetic fields. Contrary to both CT and μCT, this approach requires a large particle accelerator, and is not standard medical or laboratory equipment[Aleksandar: ref]. The added complexity means that SRμCT can offer an even better spatial resolution of up to 0.1 μm. The resulting beams are high in brilliance and collimation which gives a very clear signal. Its mono-energetic nature also means that images are not subject to artifacts from beam-hardening.

[Aleksandar: Can we confirm whether data was acquired at the ESRF and at which beamline? Also which energies were used? All this could be important for reproducibility.]
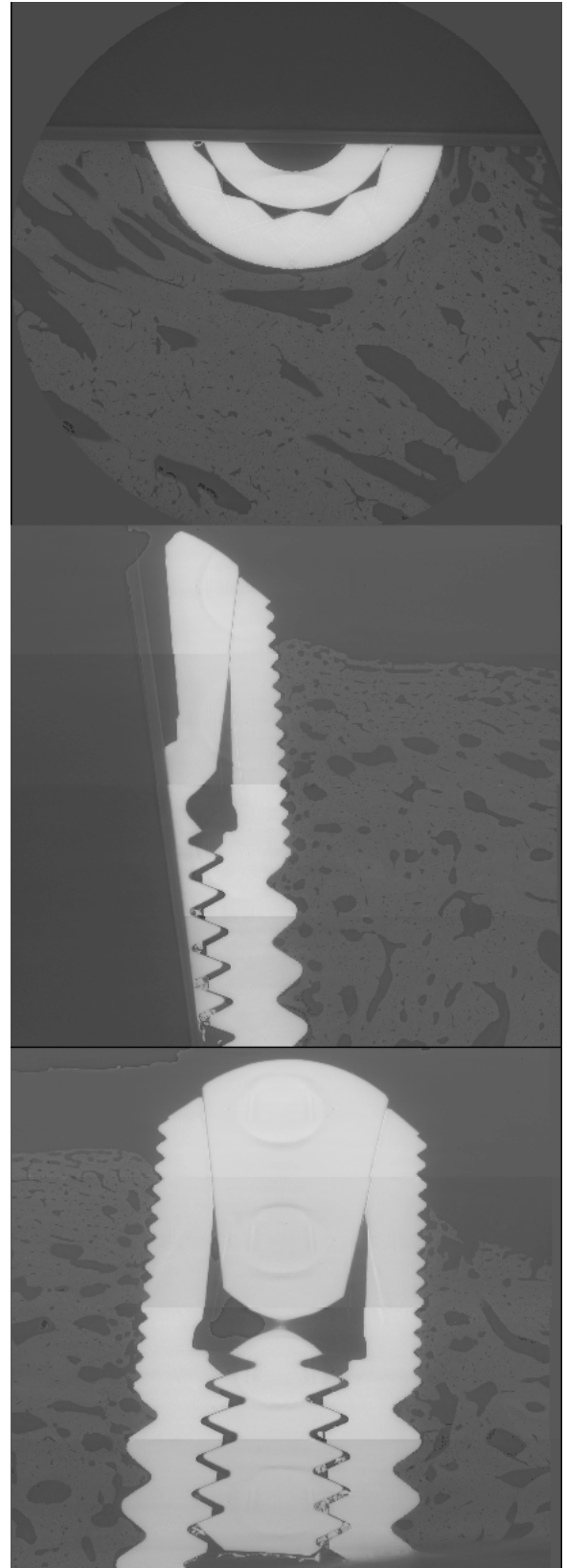

Fig. 1. [Aleksandar: Temporary example figure of sample in x,y,z dimension. It could perhaps even be manually annotated (meaning we can indicate roughly what regions correspond to: resin, air, implant, bone), and related to the physical scale mentioned above? Maybe as simple as overlaying a ruler with the given scale?]

[Aleksandar: Was filtered backprojection used to do reconstruction, and who has done that? Was it done at ESRF?]

Image data

A single image sample contains voxels with of spatial resolution 1.875μm. The physical size of a sample is about 6.5mm, which makes the raw dimensions of a single image (3480, 3480, 3384) pixels. For computational purposes, this has been cropped to be divisible by $2^5 = 32$. A full image sample is further split into 4-6 sub-volumes through the height of the implant. This gives a size of $(3456, 3456, 810)$ pixels per sub-volume, where the last axis gets stacked for a full volume.

[Aleksandar: OBS: 846 i rå størrelse, 810 er efter volumematching.]

[Aleksandar: Important to explain a bit about how the samples were cut during acquisition. How were the samples secured in order not to be shifted too much etc.]

Physical effects, noise and artifacts

Noise in tomography is unavoidable, and it makes segmentation harder. Matarials may be well separated from certain angles in the 3d-reconstructed image, but overlap from others. Some noise like that corrected by flat-field correction is very uniformly distributed across images. Some noise is however very spatially dependent on its sorrounding regions. Since we know the compositions of the materials being imaged, we can counter some of these effects during segmentation. The noise effects manifest themselves as numerical shifts in voxel-values as a function of their position. This is a direct result of a misrepresented attenuation along the axis the X-rays are passing.

[Aleksandar: perhaps we should mention at what energies the data is taken. This helps to narrow which types of effects play into the data.]

Low energy rays contribute mostly with noise from scattering effects. A ray will propagate through a material, get scattered and diffract from its initial trajectory. This gives a misrepresentation of the attenuation along its initial trajectory.

Streaking artifacts from dense implant region, but also in the transition from bone to softer tissue.

...

For SRμCT a high photon flux allows for very short exposure times (Rack et al., 2020). This can help counter noise from suboptimal counting statistics(Vidal et al., 2005).

* Gå fra brede effekter som viser sig i hele billedet (og er mere generelle) -¿ Til de mere specifikke effekter som er mere specifikke for vores case

* genskær fra voxels mørke effekter modsat lysere effekter fra beam-hardening (x-rays er inverteret)

Forklare hvorfor vi ser mørke områder, særligt at det mørke lægger sig omkring implantatet, men at det så aftager mod knoglen, for så at blive kraftigere og bredere helt ved knoglen.. nok refraktion osv. [Aleksandar: OBS: before talking about specific noise in our data, we should probably include one or more examples of noise that shows how the segmentation is made harder due to this noise.]

Solutions

[Aleksandar: Work-in-progress]

Individual materials are segmented from the full image, which is represented by their respective histograms.

$$H(x, v) = \sum_{m=1}^{n} g_m(x, v) + r(x, v) \tag{1}$$

Where g_m represents a histogram for materials $m \in \{1, n\}$, and $r(x, v)$ is incorrectly identified remaining region.

We find the probability for a certain material as:

$$p(m|x, v) = \frac{g_m(x, v)}{H(x, v)} \tag{2}$$

We then have a single distribution is given by a piecewise polynomial:

$$g_m(x, v) = a_m(x)e^{-b_m(x)|v - c_m(x)|^{d_m(x)}} \tag{3}$$

Where a is the height, b is the width, c is the centre and d is the exponent.

If we were to look at the distributions for individual slices, we would get too much variance. Instead we would like to fit the individual coefficients to get a smooth function.

Miscellaneous

We shall go through these subjects and explain what was done and how + why. We briefly explain how the method works.

- Volume matching

- Find implant mask

- EDT (Euclidean distance transform)

- Gauss

- Gauss + EDT

- Hist(x,y,z,r)

- Find lines / ridges

- Get distributions

- Beskrive processen under GUI trinvist

- Segment materials from distributions

- Bayesian combination of materials from their distributions

Probabilities

[Aleksandar: Work-in-progress]

Ud fra et 3d-billede (volumen), kan vi tælle os til de enkelte fordelinger

p(I), p(I—x), p(I—y), p(I—z), p(I—r), hvor $r = \sqrt{(x - x_0)^2 + (y - y_0)^2}$

ved at finde peaks og fitte distributioner kan vi da finde approksimationer til

p(c—I), p(c—I,x), p(c—I,y), p(c—I,z), p(c—I,r)

hvor c er klasserne, fx knogle, blodåre, væv, ...

Vi vil gerne finde kombinationsfordelinger som kan klassificere voxels ved brug af mere information end kun intensiteten - blandt andet hvor voxelen befinder sig.

Ud fra fx p(c—I,x) og p(c—I,y) og ... vil vi gerne approksimere p(c—I,x,y,z,r) uden at skulle repræsentere den eksplicit som et kæmpe volumen.

Dette vil vi gøre ved at bruge betinget uafhængiged. [Aleksandar: Evt inkludere bevis for at det er validt. Ellers så blot forklare hvordan sandsynlighederne sammensættes og bruges.]

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Table 1. Summary of different works pertaining to face and speech fusion

Study	Algorithm used	DB Size	Covariates of interest	Top individual performance	Fusion Performance
UK-BWG (Mansfield et al., 2001)	Face, voice: Commercial	200	Time: 1–2 month separation (indoor)	TAR* at 1% FAR$^\#$ Face: 96.5% Voice: 96%	–
Brunelli (Brunelli and Falavigna, 1995)	Face: Hierarchical correlation Voice: MFCC	87	Time: 3 sessions, time unknown (indoor)	Face: TAR = 92% at 4.5% FAR Voice: TAR = 63% at 15% FAR	TAR =98.5% at 0.5% FAR
Jain (Jain et al., 1999)	Face: Eigenface Voice: Cepstrum Coeff. Based	50	Time: Two weeks (indoor)	TAR at 1% FAR Face: 43% Voice: 96.5% Fingerprint: 96%	Face + Voice + Fingerprint = 98.5%
Sanderson (Sanderson and Paliwal, 2002)	Face: PCA Voice: MFCC	43	Time: 3 sessions (indoor) Noise addition to voice	Equal Error Rate Face: 10% Voice: 12.41%	Equal Error Rate 2.86%
Proposed study	Face, voice: Commercial	116	Location: Indoor and Outdoor (same day) Noise addition to eye coordinates	TARs at 1% FAR Indoor-Outdoor Face: 80% Voice: 67.5%	TAR = 98% at 1% FAR

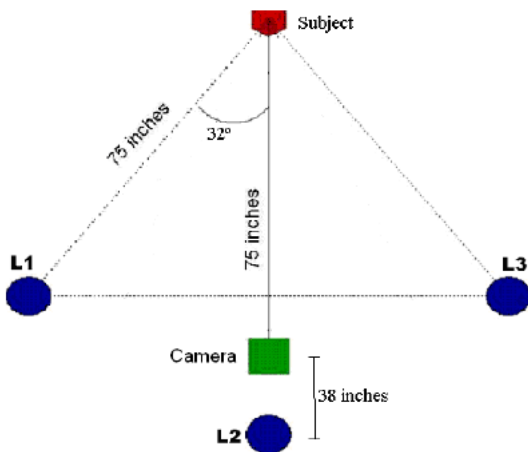*TAR–True Acceptance Rate　　　$^\#$ FAR–False Acceptance Rate

Fig. 2. Studio setup for capturing face images indoor. Three light sources L1, L2, L3 were used in conjunction with normal office lights.

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   2..1 A subentry

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References

Rack, A., Stroebel, J., Rack, T., Dabin, Y., Knabe, C., Stiller, M., Coan, P., Bleuet, P., 2020. Tomopress-in situ synchrotron-based microtomography under axial load. Instruments 4, 11. doi:`10.3390/instruments4020011`.

Vidal, F.P., Létang, J.M., Peix, G., Cloetens, P., 2005. Investigation of artefact sources in synchrotron microtomography via virtual x-ray imaging. Nuclear Instruments and Methods in Physics Research B 234, 333–348. doi:`10.1016/j.nimb.2005.02.003`.

Supplementary Material

Supplementary material that may be helpful in the review process should be prepared and provided as a separate electronic file. That file can then be transformed into PDF format and submitted along with the manuscript and graphic files to the appropriate editorial office.