A Realistic Digital Phantom for Perfusion C-arm CT based on MRI Data

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Introduction

- **CT Perfusion** (CTP) is an important imaging modality for the diagnosis of **ischemic stroke.**
- **Flat Detector CT Perfusion** (FD-CTP) enables C-Arm systems to measure brain perfusion **interventionally**.

Advantages of FD-CTP

- **Interventional availability**
- **Saves time** if interventional treatment is performed (e.g. Intra-arterial thrombolysis)
- Isotropic **full brain** coverage.

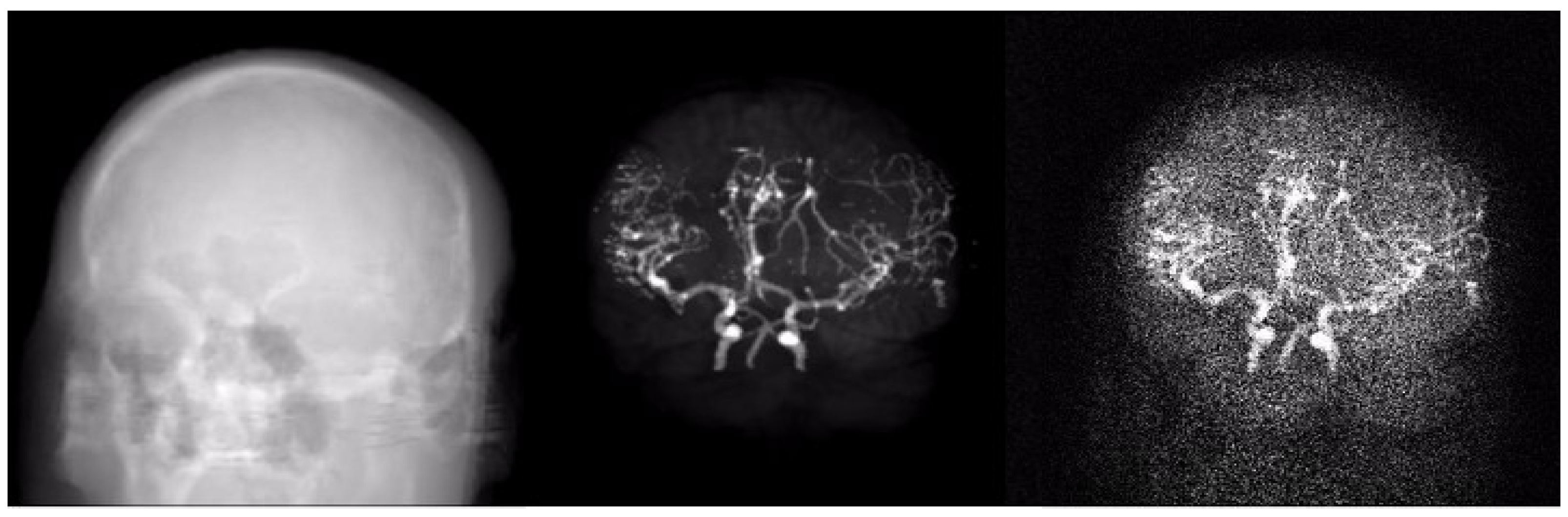
Challenges of FD-CTP

- **Slower** and **non-continuous** rotation
- Low angular **sampling**
- Low dose / high **noise**
- **Patient movement**

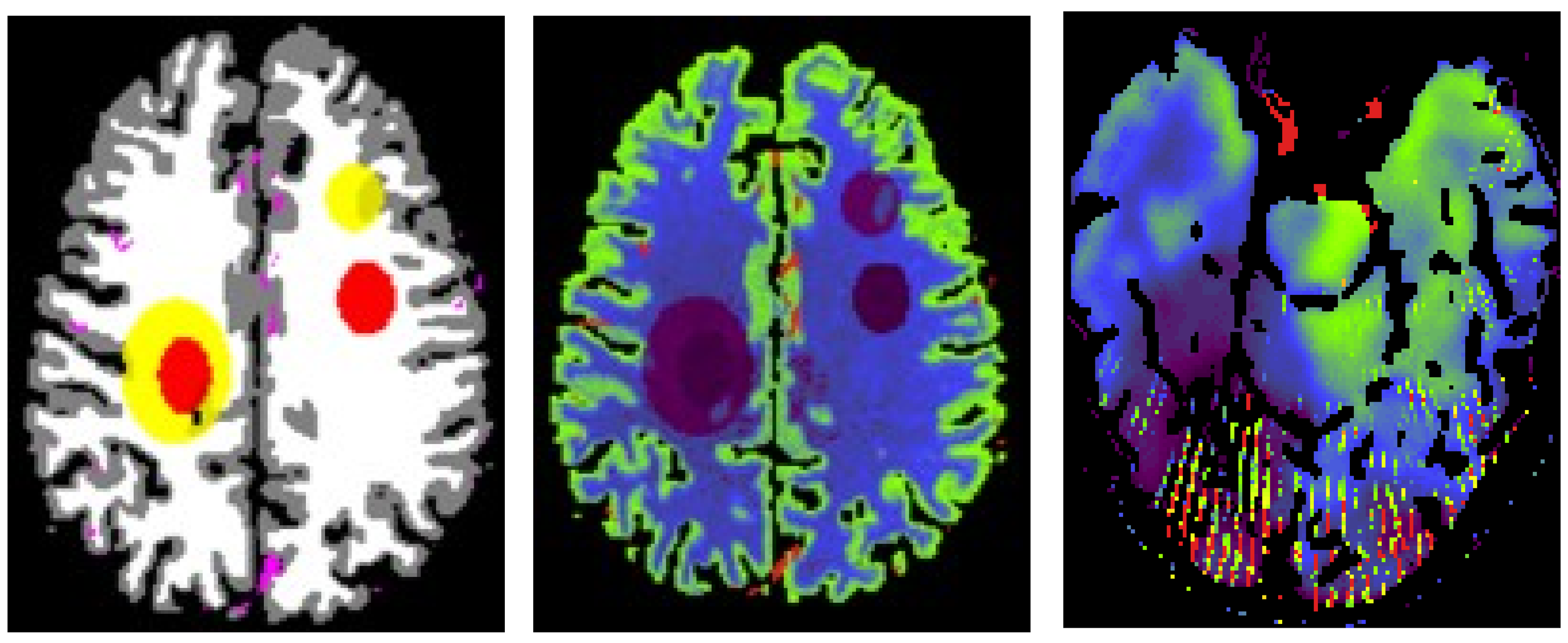
The best (FD-)CTP algorithm is the one which is most resilient to artifacts.

The phantom

- This work presents a **digital phantom** for evaluation of CTP and FD-CTP reconstruction and filtering algorithms.
  → Models both physiology
  → Models reconstruction artifacts
- The software and data are freely available for download
  http://www5.cs.fau.de/research/data/



Forward Projections Left: With skull; Center: Without skull; Right: Poisson noise No skull



The phantom. Left: annotated regions for infarct core and penumbra; Center: the ground truth CBF; Right: a slice of a CBF map from the base of the skull after reconstruction using the FDK-JBF algorithm [3], which is corrupted by realistic streak artifacts

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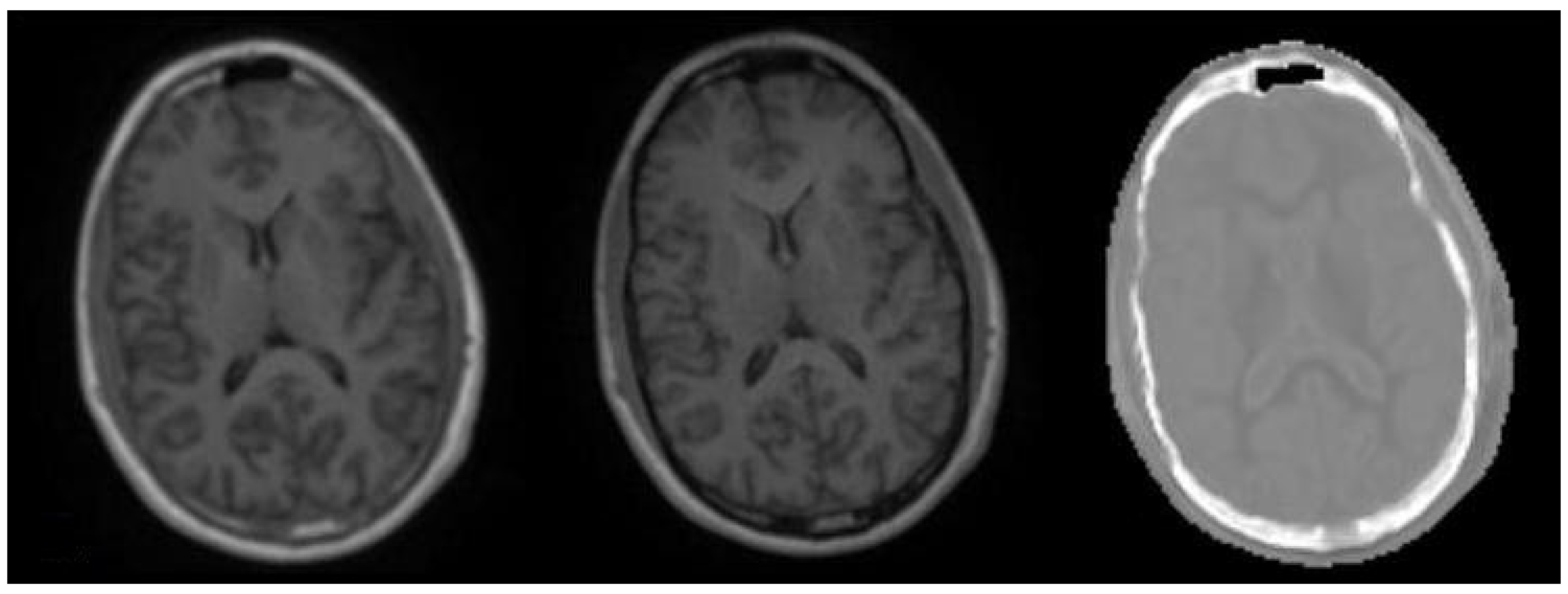
Motivation

- Building complex physical phantoms is hard in case of perfusion because perfusion occurs on a very small scale at capillary level.
- Prior work by **Riodan et al.** [1] suggests a digital **CTP phantom** of realistic complexity **based on MRI data**.
- A dense physiological model prevents a bias towards exaggerated amounts of regularization.
- Reconstruction algorithms must be **resilient** to large amounts of **noise** and **reconstruction artifacts**.

→ **Evaluation must account for artifacts**

Design

- Build a digital phantom which uses MRI not only to simulate dynamics, but also for anatomy.
- Simulate a pseudo-CT from dedicated MR sequences (Ultrashort Echo Time).
  Approach by Navalpakkam et al. [2], originally intended to create attenuation maps for PET/MRI.



Pseudo-CT estimation from a volunteer acquisition. Left: First Echo: UTE-TE1 (0.07ms); center: Second Echo: UTE-TE2 (2.46ms); right: MR-predicted CT

- MATLAB tool to annotate regions with reduced and highly reduced perfusion to simulate stroke.
- Simulate residue functions based on T1 weighted MR:

Perfusion at voxel x — Normalized T1 MR

$$PV(x) = P(x) + NMR(x) \cdot DP(x)$$

Stroke Annotation — Controls amount of deviation

- Simulate patient movement during forward projection. Streak artifacts do not cancel out during subtraction.
- The result is a realistic digital phantom:
  - Dense physiological model
  - Anatomical structures (i.e., Bones)
  - Possibility to simulate streak artifacts

References

[1] Alan J. Riordan et al. Validation of CT brain perfusion methods using a realistic dynamic head phantom. Med Phys, 38:3212–3221, 2011.
[2] Bharath K. Navalpakkam, Harald Braun, Torsten Kuwert, and Harald H. Quick. Magnetic Resonance-Based Attenuation Correction for PET/MR Hybrid Imaging Using Continuous Valued Attenuation Maps. Invest Radiol, 48(5):323–332, 2013.
[3] Michael T. Manhart, Andreas Fieselmann, Yu Deuerling-Zheng, and Markus Kowarschik. Iterative Denoising Algorithms for Perfusion C-arm CT with a Rapid Scanning Protocol. In IEEE, editor, Proceedings of 2013 10th IEEE International Symposium on Biomedical Imaging: From Nano to Macro, pages 1223–1227, 2013.