Computational Imaging and Tomography: PDM-DART Implementation (Paper 4) Phantom generation

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1 Introduction

The PDM-DART method [3] is designed to adaptively estimate discrete grey levels and segmentation thresholds for image reconstruction. However, the method primarily focuses on segmenting images based on fixed and free pixels, where homogeneous regions are kept unchanged while other regions are iteratively refined. In real-world scenarios, objects often exhibit continuous intensity variations, such as soft tissues in CT scans, which may not fit neatly into this discrete segmentation framework.

To evaluate PDM-DART's performance in such cases, we will use phantoms with smooth intensity transitions (about 256 grey levels), one of the examples is the figure 1 an onion-like gradient structure in the center of the Basic Phantom. These phantoms will allow us to observe whether PDM-DART can handle continuous variations effectively or if it forces artificial quantization into discrete grey levels. Additionally, along with testing grey-level variations, we aim to assess segmentation performance on sharp edges and overlapping structures, which will provide further insight into how the method distinguishes between fixed and free pixels in complex spatial arrangements. These evaluations will help determine the strengths and limitations of PDM-DART.

2 Phantom Description

We have divided our focus among four types of phantoms each designed to evaluate different aspects of segmentation and reconstruction accuracy:

- **Basic Phantom**: A star shaped phantom to evaluate segmentation accuracy for sharp edges and grey-level transitions. This is to test our first phase of implementation of the method. It is constructed around a disk shape, then the triangles are made by dividing into equal angles using sine and cosine functions.

  The inner ellipses have increasing intensity values starting from 0.3, with each subsequent ellipse increasing by an iterative factor of 0.1 to create a grey level gradient effect. In terms of adding noise, We have included Gaussian and Poisson noise.

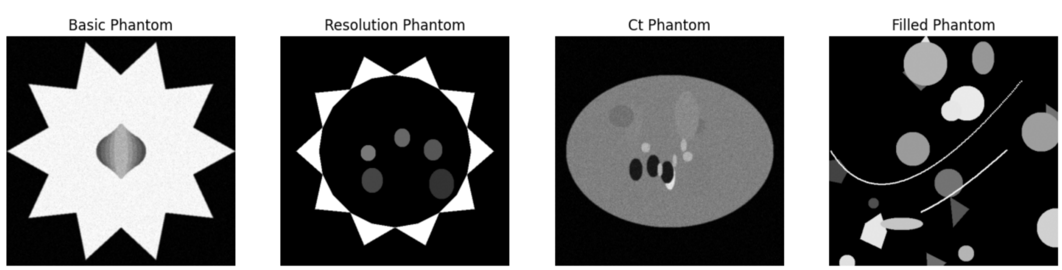

Figure 1: Simulated phantoms to test PDM-DART

Figure 2: The real phantom of CT scan from human body [1]

- **Resolution Phantom**: In this phantom, we have added small ellipses with different grey levels to the basic phantom's star structure. This is to understand how the reconstruction will highlight high-frequency structures placed closed together.
- **CT Phantom**: This is the enhanced verison of Resolution phantom. The CT Phantom is designed to look like the simulation of real CT scan as seen in figure 2of cross-section of human body like reproductive system , with different shapes representing tissues, bones, and air pockets. The simulated CT is made on an ellipse (soft tissue, intensity 0.5), with random smaller ellipses acting as organs (0.4 – 0.6). A spinal structure (high intensity, 0.9) and air pockets (low intensity, 0.1) are included to test how well the method separates different materials. Blood vessel-like structures (intensity 0.7) are also added. Shapes are placed randomly to make the test more realistic, and noise such as Guassian and Poisson noise is added to simulate real CT scans.
- **Filled Phantom**: This is specifically designed to see how it handles less homogeneous areas which are not defined by specific boundaries. It contains random shapes like disk, ellipses, and polygons, each with different grey intensity levels (0.2 – 0.9). Curved lines (Bezier curves) are added to look like blood vessels, testing how the method handles smooth structures and how would it assign to fixed and free pixels. The shapes are placed randomly, often overlapping, to make segmentation harder.We can choose among Guassian and Poisson Noise to make it more realistic.

3 Future work on Phantom generation

The above phantoms were designed in 2D, and we aim to extend our approach by incorporating 3D phantom structures for more advanced testing.

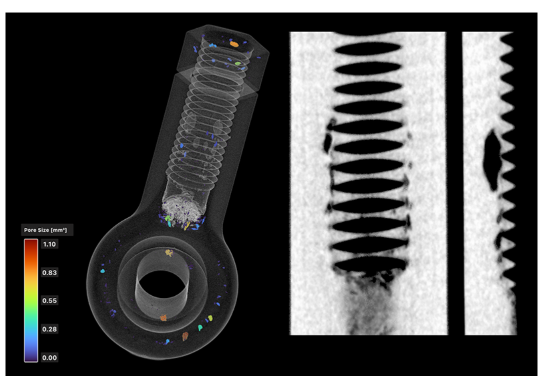

Figure 3: The example industrial image of voids detection around the threading [2].

Other than medical imaging, PDM-DART has potential applications in various field like quality control and inspection in Figure 3 applied in industrial area to enhance inspection techniques over traditional visual inspection, in this case during phantom generation we could also focus on some mechanical-like phantoms for future exploration .

Forward Projection: Currently the paper[3] has focused on parallel beam projection. We will look into the performance with fan beam projection as well.

References

[1] Johner Institute. Phantoms in medical technology, 2025. Accessed: 2025-03-12.

[2] Lumafield. Industrial ct vs. traditional inspection techniques. 2025. Accessed: March 12, 2025.

[3] Wim van Aarle, Kees J. Batenburg, and Jan Sijbers. Automatic parameter estimation for the discrete algebraic reconstruction technique (dart). *IEEE Transactions on Image Processing*, 21(11):4608–4621, 2012. PMID: 22752136.