

Description of Functions

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Key Functions I: Create Digital Phantom (digital_phantom.py)

Creates disk, resolution, low-contrast phantom.

disk_phantom

Description: Creates a disk phantom.

Parameters:

- `fov` (tuple): Field of View (FOV) in millimeters (mm).
- `radius` (tuple): Circle radius in millimeters (mm).
- `center` (tuple, optional): Center coordinates of the disk in millimeters (mm). Default is (0,0).
- `theta` (float, optional): Rotation angle in degrees. Default is 0.
- `matrix_size` (tuple, optional): Matrix size in number of pixels. Default is (64,64).
- `intensity` (float, optional): Intensity of the disk. Default is 1.
- `noise_std` (float, optional): Standard deviation of complex Gaussian noise. Default is 0.

Returns:

- `kspace` (ndarray): Complex k-space representation of the disk.
- `disk` (ndarray): Image of the disk.

Reference: [Digital Reference Objects GitHub repository](#)

resolution_phantom

Description: Creates a resolution phantom.

Parameters:

- `fov` (tuple): Field of view in millimeters (mm).
- `radius` (tuple): Radii of individual holes in millimeters (mm).
- `center` (tuple, optional): Center of the phantom in millimeters (mm). Default is (0,0).
- `array` (tuple, optional): Number of holes in x,y dimension. Default is (4,4).
- `matrix_size` (tuple, optional): Matrix size of k-space & image. Default is (64,64).
- `intensity` (float, optional): Intensity of the image. Default is 1.

- `noise_std` (float, optional): Standard deviation of additive complex Gaussian noise. Default is 0.1.

Returns:

- `kspace_res` (ndarray): Complex k-space.
- `res` (ndarray): Image of resolution phantom.

low_contrast_phantom

Description: Creates a low contrast phantom.

Parameters:

- `fov` (tuple): Field of view in millimeters (mm).
- `radius_range` (tuple): Smallest and largest radii in millimeters (mm).
- `center` (tuple, optional): Center of the phantom in millimeters (mm). Default is (0,0).
- `nspokes` (int, optional): Number of spokes. Default is 10.
- `spoke_dist` (float, optional): Distance between phantoms within one spoke. Default is 20.
- `disk_per_spoke` (int, optional): Number of disks per spoke. Default is 3.
- `matrix_size` (tuple, optional): Matrix size. Default is (64,64).
- `intensity` (float, optional): Intensity of background phantom. Default is 1.
- `contrast` (float, optional): Additive intensity of the foreground phantoms. Default is 0.1.
- `noise_std` (float, optional): Noise standard deviation. Default is 0.1.

Returns:

- `kspace_lc` (ndarray): K-space of low contrast phantom.
- `lc` (ndarray): Image of low contrast phantom.

Key Functions II: Evaluation Metrics (`evaluation_metrics.py`)

geometric_accuracy

Description: Measure the geometric accuracy of a disk phantom.

Parameters:

- `disk` (ndarray): (M, N) Image to measure.
- `fov` (tuple): Field of view in millimeters (mm) (`fov_x`, `fov_y`).
- `radius` (tuple): Ground truth radius in millimeters (mm).
- `center` (tuple): Ground truth center in millimeters (mm).
- `plot` (bool, optional): Plot predicted axes, center, and bounding box. Default is False.

Returns:

- `max_percentage_error` (float): Maximum percentage error of major axis and minor axis compared with ground truth.
- `eccentricity` (float): Equals to 0 when input image is circle, range [0, 1).

intensity_uniformity

Description: Measure the intensity uniformity using a disk phantom.

Parameters:

- `disk` (ndarray): (M, N) Image to measure.
- `fov` (tuple): Field of view in millimeters (mm) (`fov_x`, `fov_y`).
- `radius` (tuple): Ground truth radius in millimeters (mm).
- `center` (tuple): Ground truth center in millimeters (mm).
- `intensity` (float): Ground truth intensity.
- `plot` (bool, optional): Plot predicted axes, center, and bounding box. Default is False.
- `location_known` (bool, optional): Consider the center of the disk known or unknown. Default is True. If known, use the known center to define ROI. If unknown, use thresholding to detect ROI.

Returns:

- `intensity_bias` (float): Intensity bias, percentage error of mean intensity compared with ground truth.
- `intensity_uniform` (float): Intensity uniformity.

percentage_ghosting

Description: Measure the percentage ghosting of a disk phantom.

Parameters:

- `disk` (ndarray): (M, N) Image to measure.
- `fov` (tuple): Field of view in millimeters (mm) (`fov_x`, `fov_y`).
- `center` (tuple): Ground truth center in millimeters (mm).
- `intensity` (float): Ground truth intensity.
- `plot` (bool, optional): Plot predicted axes, center, and bounding box. Default is False.

Returns:

- `ghosting_ratio` (float): Ghosting ratio, percentage image ghosting.

sharpness

Description: Sharpness using the edge spread function of a disk phantom.

Parameters:

- `disk` (ndarray): Disk image.
- `fov` (tuple): FOV of the disk.
- `radius` (tuple): Radius of the disk.
- `center` (tuple): Center of the disk.
- `plot` (bool, optional): Plot figures for debugging. Default is False.
- `fit` (bool, optional): Whether to fit the edge spread function to sigmoid. Default is False.

Returns:

- `fwhm` (float): Full-width-half-maximum of the fitted Lorentzian function.
- `mal_val` (float): Maximum value of the fitted Lorentzian function.

snr_dual_image

Description: SNR measurement using two disks.

Parameters:

- `disk1` (ndarray): 1st disk phantom.
- `disk2` (ndarray): 2nd disk phantom.
- `fov` (tuple): FOV of the disk phantoms in mm.
- `radius` (tuple): Radius of the disk phantoms in mm.
- `center` (tuple): Center of the disk phantoms in mm.

- `plot` (bool, optional): Plot for debugging. Default is False.
- `signal_roi_width` (int, optional): Signal ROI width. Default is 7.
- `noise_roi_width` (int, optional): Noise ROI width. Default is 13.

Returns:

- `snr` (float): SNR.

high_contrast_resolution

Description: High contrast resolution measurement using resolution phantom.

Parameters:

- `res` (ndarray): Image of resolution phantom.
- `fov` (tuple): Field of view in mm.
- `radius` (tuple): Radii of individual holes in mm.
- `center` (tuple, optional): Center of the phantom in mm. Default is (0,0).
- `array` (tuple, optional): Number of holes in x,y dimension. Default is (4,4).
- `plot` (bool, optional): Plot for debugging. Default is True.

Returns:

- `pixel_size` (tuple): Pixel size in both directions.
- `number_of_resolved_line` (tuple): Number of resolved lines in both directions.

threshold_determination

Description: Determine the threshold for signal present and signal absent patches. **Parameters:**

- `radius` (float): Radius of disk in mm.
- `noise_std` (float): Standard deviation of noise.
- `patch_size` (int): Matrix size of the patch.
- `fov` (tuple): FOV of the original resolution phantom.
- `matrix_size` (tuple): Matrix size of the original resolution phantom.
- `n_patch` (int): Number of patches to generate for signal present or signal absent category.
- `contrast` (float): Contrast of the resolution phantom.
- `plot` (bool, optional): Plot for debugging. Default is False.

Returns:

- `thre` (float): Threshold for this disk radius, noise, patch size, contrast.
- `acc_max` (float): Maximum accuracy corresponding to this threshold.

low_contrast_detectability

Description: Low contrast detectability using the low contrast phantom.

Parameters:

- `lc` (ndarray): Low contrast phantom image.
- `fov` (tuple): Field of view in millimeters (mm).
- `radius_range` (tuple): (min_radius, max_radius) of disks.
- `center` (tuple): Center of the phantom.
- `intensity` (float, optional): Intensity of background. Default is 1.
- `nspokes` (int, optional): Number of spokes. Default is 10.
- `spoke_dist` (float, optional): Distance between disks within a spoke in millimeters (mm). Default is 20.
- `disk_per_spoke` (int, optional): Number of disks per spoke. Default is 3.
- `plot` (bool, optional): Plot the result. Default is True.
- `contrast` (float, optional): Contrast of the disks. Default is 0.3.
- `noise_std` (float, optional): Standard deviation of the additive Gaussian noise. Default is 0.0.

Returns:

- `num_complete_spoke` (int): Number of complete spokes, main metric.
- `num_corr` (ndarray): Number of correlated locations for each disk.