# Digital Reference Object simulation for validation of WAD-QC MR modules – Documentation

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**Purpose:**
This generates synthetic magnetic resonance (MR) images, for the purpose of validating different modules in the WAD-QC MR quality control system. The generated digital reference objects (DRO) simulate simple structures, such as an ellipse or rectangle, and allow for controlled variations in geometry, signal-to-noise ratio (SNR), image uniformity (IU), and ghosting. These DRO's can be used to validate the WAD-QC MR modules following installation or system updates.

## Function Overview

### 1. generate_mr_geometryXY()

**Purpose:**
Generates a 2D elliptical phantom image to validate *in-plane geometry* (XY).

**Intended WAD-QC MR_ACR submodule:**
geometry_xy.

**Key Features:**
- Simulates an ellipse with configurable diameter, center shift, and pixel size.
- Takes absolute values after adding Gaussian noise to simulate realistic MR noise conditions of magnitude data.
- Configurable smoothing is added to the image.
- Annotates the image with simulation parameters.
- Saves the result as a PNG image.

**Parameters:**
- image_size: Size of the square output image in pixels (default: 512).
- diam_x, diam_y: Diameters of the ellipse in mm (default: 190 mm each). Setting the diameters to equal values results in a circular phantom.
- pixel_size: Pixel size in mm (default: [1, 1]).
- shift: Center shift of the ellipse in mm (default: [0, 0]).
- SNR: Signal-to-noise ratio (default: 40).
- sigma: Gaussian smoothing parameter (default: 1).

## 2. generate_mr_geometryZ()

**Purpose:**
Creates a rectangular phantom image for testing *through-plane geometry* (Z-axis).

**Intended WAD-QC MR_ACR submodule:**
geometry_z.

**Key Features:**
- Simulates a rotated rectangle onto a dark background.
- Takes absolute values after adding Gaussian noise to simulate realistic MR noise conditions of magnitude data.
- Allows rotation of the rectangle to test angle measurements.
- Annotates the image with simulation parameters.
- Saves the result as a PNG image.

**Parameters:**
- image_size: Size of the square output image in pixels (default: 512).
- rect_size: Rectangle size in mm [width, height] (default: [190, 147.5]).
- pixel_size: Pixel size in mm (default: [0.488, 0.488]).
- shift: Center offset in mm (default: [0, 0]).
- SNR: Signal-to-noise ratio (default: 100).
- angle: Rotation angle in degrees (default: 0°).

## 3. generate_mr_SNR_IU_GP_phantom()

**Purpose:**
Generates a phantom to validate SNR, Image Uniformity (IU), and Ghosting Percentage (GP).

**Intended WAD-QC MR_ACR submodules:**
signal_noise_ratio, image_uniformity, ghosting.

**Key Features:**
- Simulates an ellipse with configurable diameter and pixel size.
- Adds noise according to a configurable SNR.
- Generates small circular ROIs with adjusted intensity within the phantom to simulate uniformity tests.
- Adds signal in specified regions in the background to simulate ghosting artifacts.
- Saves the result as a PNG image.

**Parameters:**
- image_size: Size of the square output image in pixels (default: 512).
- diam_x, diam_y: Diameters of the ellipse in mm (default: 190 mm each). Setting the diameters to equal values results in a circular phantom.
- pixel_size: Pixel size in mm (default: [1, 1]).
- SNR: SNR within the phantom (default: 195).
- IU: Image Uniformity percentage (default: 68).
- GP: Ghosting Percentage (default: 0.5%).

## 4. generate_mr_B0_map_phantom()

**Purpose:**
Creates a simulated B0 field map using synthetic phase and magnitude images.

**Intended WAD-QC MR_ACR submodule:**
B0_uniformity

**Key Features:**

- Simulates an ellipse with configurable diameter and pixel size.
- Introduces spatial B0 field inhomogeneities using phase shifts in circular ROIs within the phantom.
- Outputs multiple images: two phase images (with different echo times) and a corresponding magnitude image.
- Saves the result as PNG images.

**Parameters:**

- image_size: Image size in pixels (default: 128).
- diam_x, diam_y: Ellipse dimensions in mm (default: 80 mm each).
- pixel_size: Pixel size in mm (default: [2, 2]).
- B0_uniformity_ppm: Target inhomogeneity range in ppm (default: 1.2).
- dTE: Echo time difference in ms (default: 3.04 ms).
- B0: Magnetic field strength in Tesla (default: 1.5 T).

## 5. replace_dicom_pixel_data()

**Purpose:**
Replaces the pixel data in an existing DICOM file with image data from a PNG file.

**Key Features:**

- Supports 8-bit and 16-bit DICOM images.
- Automatically scales PNG data when necessary to match DICOM bit depth.
- Preserves all DICOM metadata except pixel data.
- Optionally sets RescaleSlope to 1 for standardized intensity scaling.
- Saves the result as a new DICOM file.

**Parameters:**

- dicom_path: Path to the original DICOM file.
- png_path: Path to the replacement PNG image (ideally grayscale).
- output_path: Path where the updated DICOM file will be saved.
- set_rescale_slope: If True, sets the RescaleSlope DICOM tag to 1.image_size:

**Output:**
None (a new DICOM file is saved to output_path).

# General Notes

- All phantom images are saved in **PNG format**.
- Text annotations with simulation settings are embedded in the pixel data of each image.
- Gaussian noise is used to approximate real MR acquisition conditions. To avoid negative values, the square root of each voxel is taken.
- Pixel value clipping is handled automatically to remain within 8-bit or 16-bit image limits, depending on the phantom type.

# Dependencies

This script relies on the following Python packages:

- numpy
- matplotlib
- PIL (Pillow)
- pydicom (not used directly in current functions)
- scipy.ndimage

# Results

Below are the results of the WAD-QC MR module after processing the simulated DRO's using the described code.

## 1. geometry_xy

**Simulated parameters:**
X diameter = 190 mm
Y diameter = 190 mm
shift = 0x0 mm
SNR = 40
σ = 1

**WAD-QC results:**
X diameter = 189.90 mm
Y diameter = 190.07 mm
Centre location at 256.00 255.90

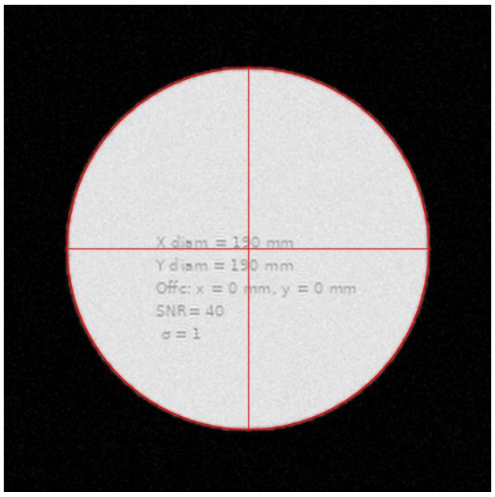


*Figure 1: fitted ellipse by WAD-QC module.*

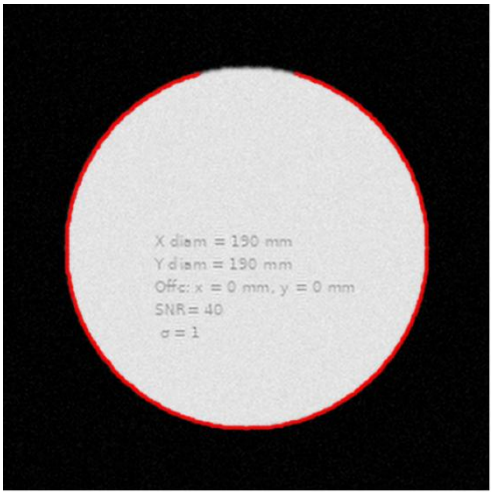


*Figure 2: detected edges by WAD-QC module.*

## 2. geometry_z

**Simulated parameters:**
rect_size = 190x147,5 mm
shift = 0x0 mm
SNR = 40
angle = 5°

**WAD-QC results:**
Geometry Z length = 147.46 mm
Geometry Z rotation = 5.10°

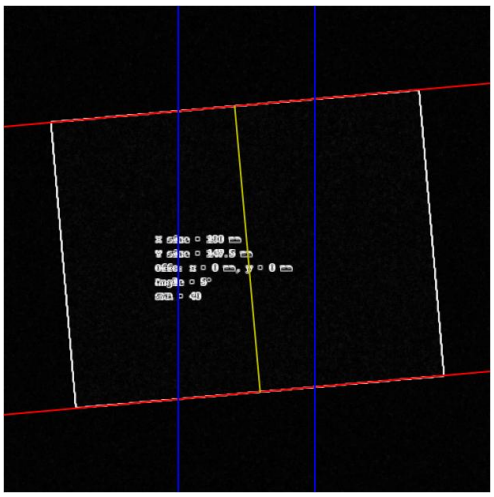

*Figure 3: WAD-QC edge detection.*

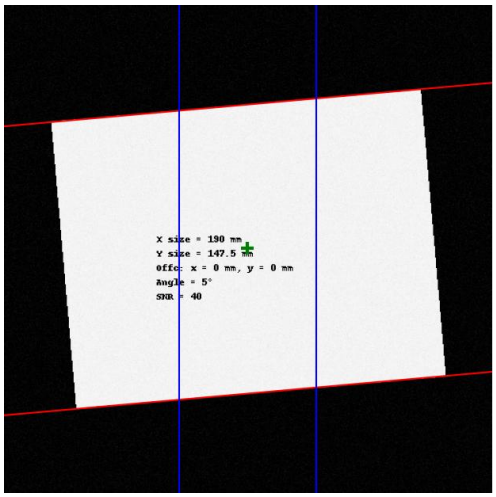


*Figure 4: fitted edges by WAD-QC.*

## 3. signal_noise_ratio

**Simulated parameters:**
SNR = 215.0

**WAD-QC results:**
SNR = 215.6

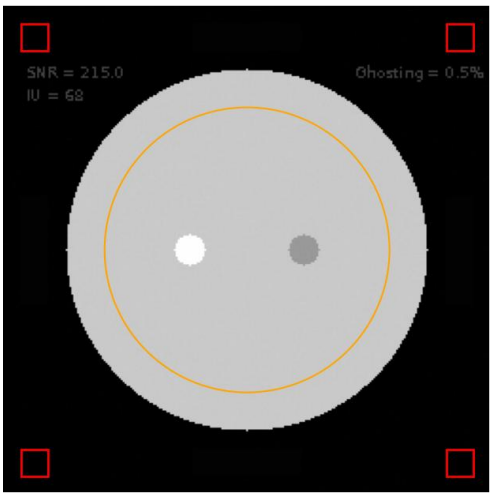


*Figure 5: ROI placement of WAD-QC module for SNR calculation.*

## 4. image_uniformity

**Simulated parameters:**
Image uniformity = 68.0%

**WAD-QC results:**
Image uniformity = 68.0%

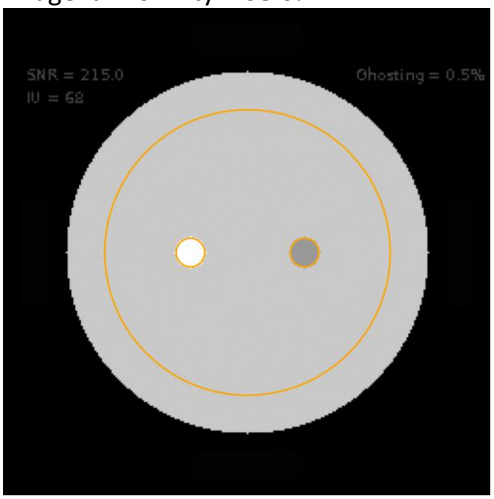


*Figure 6: ROI placement of WAD-QC module for image uniformity calculation.*

## 5. ghosting

**Simulated parameters:**
Ghosting percentage = 0.5

**WAD-QC results:**
Ghosting percentage row = 0.48
Ghosting percentage column = 0.48

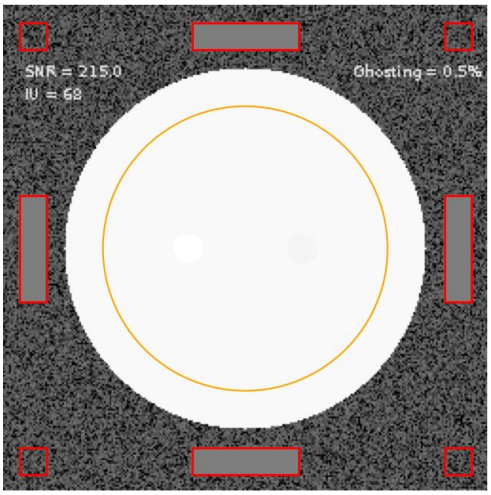


*Figure 7: ROI placement of WAD-QC module for ghosting percentage calculation.*

## 6. B0_uniformity

**Simulated parameters:**
B0 uniformity = 1.20 ppm

**WAD-QC results:**
B0 uniformity = 1.20 ppm

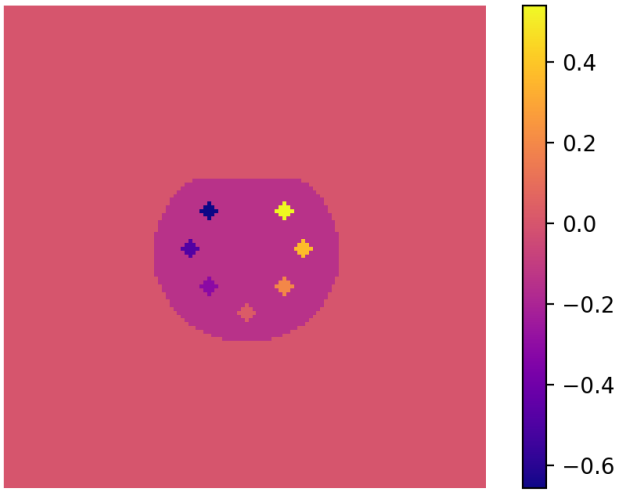


*Figure 8: Unwrapped phase map created by the WAD-QC module*