

MDT software manual (version 1.1)

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Overview

This software reduces CT metal artifacts using the Metal Deletion Technique (MDT), which works on DICOM files from any scanner. It requires a fast multi-CPU Linux server with permission to send and receive files from PACS, and may require several hours to set up. Once it is set up, it is extremely easy to use. The simplest method is to use the DICOM send feature in PACS. The images are then automatically processed, and sent back to PACS as a new series under the same accession number. Turnaround time is approximately 15 minutes (on an Intel Xeon Nehalem 2.93 GHz). Alternatively, images can be uploaded to an FTP directory, where they will be automatically processed and placed in an output directory.

MDT is not FDA approved, and is only intended for research use. It is covered by US patent 8233586.

Installation

Upgrading from version 1.0

Initialization (.ini) files from previous versions are fully compatible with the current version. To upgrade, simply replace the MDT and MDT_util executable files with the new versions.

Hardware

You will need a fast multi-CPU Linux / Unix server. Memory is not an issue. At Stanford, we have a server that has the capacity to process up to 16 slices containing metal, with a turnaround time of 15 minutes. This is a dual-CPU Intel Xeon X5575 Nehalem 2.93 GHz (4 cores per CPU), which costs around \$10k.

A faster CPU would reduce the turnaround time, and adding more CPU cores would increase the number of slices that can be processed in parallel. The number of slices that can be processed in parallel = number of servers × number of CPUs per server × number of cores per CPU × number of hyperthreads per core. If you want to run multiple servers in parallel, MDT must be installed in a directory that can be accessed from all of the servers (communication between the servers takes place via files that are placed in this shared directory).

Interface with PACS

You will need ask your PACS technical support to allow PACS to send and receive DICOM files from the MDT server. They will need the following information about the MDT server:

Host name or IP address

AETitle (a locally unique identifier for this service, for example, MDT)

DICOM receive port for the MDT server (for example, 11112)

You will need to get the following information about your PACS system:

Host name or IP address

DICOM receive port for PACS (which can be different from the DICOM receive port for your server)

Other software (optional)

The following optional software can be installed at any time, to provide additional features:

DCMtk (<http://dicom.offis.de>) which is used to send and receive DICOM files from PACS. After installation, you should test your connection to PACS.

To receive files from PACS, run:

```
storescp -od [receive directory] -ss z [receive port number]
```

To send files to PACS:

```
storescu [PACS IP address] -aet [AE title] [send port number] [DICOM file name]
```

If this does not work, there may be a firewall issue, which may require assistance from the hospital IT department to resolve.

ImageMagick (<http://www.imagemagick.org>). The `convert` command is used to convert .bmp to .png files for the FTP interface. It is not needed if you do not need png files. It is not needed for the PACS interface.

mutt and sendmail. This is only needed if you want to receive periodic status emails with the load on the server.

Web server. This is only needed if you want to see the web page listing the estimated completion times of submitted accession numbers.

Software setup

Create a user called `ct`, and place the installation file (`MDT_1.0_64bit.tar.gz` or `MDT_1.0_32bit.tar.gz`) in the directory `/home/ct/`. Run the following to unpack the files:

For 64-bit Linux:

```
gunzip MDT_1.0_64bit.tar.gz
tar xvf MDT_1.0_64bit.tar
```

For 32-bit Linux:

```
gunzip MDT_1.0_32bit.tar.gz
tar xvf MDT_1.0_32bit.tar
```

If you are running multiple servers in parallel, `/home/ct/` should be shared among all the servers (using NFS). Please set the default shell to `bash` (only necessary if you want to receive status emails).

The following files need to be edited. In addition, if you have installed the software in a directory other than `/home/ct/`, please adjust the directories listed in `MDT.ini`, `MDT_util.ini`, and `MDT_start` accordingly. In `MDT.ini` and `MDT_util.ini`, parameters and values must be separated by tabs, not spaces.

MDT.ini

Parameter	Default	Recommended value
<code>num_parallel</code>	16	number of servers × number of CPUs per server × number of cores per CPU × number of hyperthreads per core
<code>site</code>	9999	Please contact us for your site number. This is required for unique identification of studies (by site number and accession number).
<code>server_name</code>		Used to identify the server in status emails.
<code>notif_email</code>		Email address to send server status emails. If you don't want to receive emails, then delete or comment out this line.

MDT_util.ini

Parameter	Default	Recommended value
<code>site</code>		Same as <code>MDT.ini</code>
<code>send_command</code>		Replace "PACS" with the IP address or host name of your PACS system. Replace "4100" with the DICOM receive port for PACS. Replace "AETITLE" with the AETitle expected by PACS. If you don't want to send the study back to PACS, then delete or comment out this line.
<code>max_slices</code>	16	If <code>num_parallel</code> is > 16, you may want to increase this to <code>num_parallel</code> . Studies with > <code>max_slices</code> containing metal will have the slice thickness increased by up to <code>max_slice_thickness</code> .
<code>max_slice_thickness</code>	1.25	Millimeters.

Parameter	Default	Recommended value
<code>max_slices2</code>	1000	Increase this if you want to process studies with more slices containing metal.
<code>num_parallel</code>		Same as <code>MDT.ini</code>
<code>processing_time</code>	900	Processing time of a single slice on a single core in seconds. Update this to obtain more accurate estimates of completion time.

Note: The slice thickness is automatically increased up to `max_slice_thickness` (1.25 mm by default) to save time. To process thin (0.625 or 0.5 mm) slices, change `max_slice_thickness` to 0.1, then run `/home/ct/MDT_start` to restart the software. This will process all scans without converting to thicker slices.

MDT_start

In the “DICOM receive” section, change 11112 to the DICOM receive port for your server. If you are not using the DICOM receive function, then delete or comment out this line.

In the “slave calculation nodes” section, add or remove lines to match `num_parallel`. For example, if `num_parallel` is 16, you need 16 lines in this section, which reference `0_0.ini` through `0_15.ini`. (These *.ini files are used by the master calculation node to send instructions to the slave calculation nodes.) If you are using multiple servers, you can use the ssh command to start these commands on remote servers. The `/home/ct` directory must be shared with the remote servers.

MDT_stop

This kills all processes associated with the MDT calculation. If you are running multiple servers, you will need to add additional ssh commands to kill processes on the remote servers.

index_template.html

Search for “Hospital name” and replace it with your hospital’s name.

Search for “Server” and replace it with the name of your server, as listed on the PACS system.

Set your web server document root to `/home/ct/public_html/`

Place your hospital logo in `/home/ct/public_html/logo.gif`

Directory structure

`/home/ct/receive/`

DICOM files sent from PACS are stored here, where they are automatically examined and moved to `/home/ct/in/PACS/`.

`/home/ct/in/`

MDT is automatically run on *.dcm files placed in this directory (or subdirectories), and results are placed in `/home/ct/out/`. `/home/ct/out/PACS/` stores files that were sent from PACS. You can create additional subdirectories as desired. **By default, files are automatically deleted after processing.** In addition, any blank directories more than 1 level below this directory are deleted. For example, `/home/ct/in/PACS/study1/` is deleted if it is empty, but `/home/ct/in/PACS/` is not deleted.

/home/ct/out/

Results of MDT run on files in /home/ct/in/ are placed here.

*_MDT.dcm are the metal artifact reduction DICOM files.

*_MDT.bmp are the metal artifact reduction images in Windows Bitmap format.

*.bmp are the original images in Windows Bitmap format.

/home/ct/public_html/

index.html in this directory is updated every few seconds with the status of jobs submitted from PACS.

MDT commands

Congratulations! You are now ready to start the MDT service.

/home/ct/MDT_start to start or restart the MDT service.

/home/ct/MDT_stop to stop the MDT service.

/home/ct/MDT_status to display the current status of the MDT service.

Using the software

DICOM send interface

Send the series of interest to your MDT server using the DICOM send function from your PACS system, or directly from the CT scanner. View the web page at /home/ct/public_html/index.html to see the estimated completion time for each submitted job. Metal artifact reduction images will automatically be sent back to PACS as a new series under the same accession number. The series number for the metal artifact reduction images is the original series number plus 1000.

If you send the entire study instead of a single series, the MDT server will pick a single series to process. If you send too many slices with metal, they will be automatically converted to thicker slices to speed processing. If you do need to process more than one series from the same accession number, you will need to wait for processing to start on the first series before sending the second series.

FTP interface

FTP files to the /home/ct/in directory, and processed images will automatically show up in the /home/ct/out/ directory. Files must have a .dcm extension.

Warning: By default, input files are automatically deleted after processing. Output files are automatically deleted after sending back to PACS. This means that if someone breaks into the MDT server, they will only be able to access scans that are currently being processed. Furthermore, if you need to restart the MDT server, the input directory will only contain files that have not yet been processed.

Troubleshooting

Please let us know what problems you have with the MDT software so that we can make installing and using the software easier for future users.

JPEG compressed DICOM files are not supported. You must first uncompress them. Using DCMtk:
`dcmdjpeg in.dcm out.dcm`

Tips for getting the best results from MDT

- Best results are obtained with small stationary implants: hip replacements, aneurysm coils, surgical clips, and dental fillings.
- Suboptimal results (loss of resolution) are obtained with large implants: pedicle screws and complex orthopedic hardware. In general, if the feature of interest can only be seen by looking through metal, then MDT tends to blur it out.
- In some cases, MDT decreases resolution or introduces new artifacts. Thus, you should always review MDT images in conjunction with the original images produced by the scanner.
- You must upload DICOM files. JPEG, GIF, TIFF, or PNG files will not work, even if you convert them to DICOM (these file formats only allow 256 grayscale levels, and they do not specify Hounsfield units).
- To reduce artifacts on coronal or sagittal images, you should perform MDT on axial slices, then reformat into the desired plane.
- The metal causing the streaks must be visible on the image. A small field of view with the metal off the edge of the image won't work.
- MDT uses a fixed Hounsfield unit cutoff of 3000 to detect metal. If the Hounsfield units are less than 3000 due to partial volume effects on small implants, then try thinner slices. If the implant material is actually less than 3000 HU, then you will need to edit the Hounsfield units before running MDT.
- By default, many scanners only output HU between -1024 and 3071. If dark streaks are below -1024 HU, then selecting the “extended HU range” option should give better results.

Key parameters to optimize (Advanced users)

The default parameters for metal artifact reduction work well for a wide range of metal implants. However, if it is necessary to optimize the image quality of a specific scan, the following are the key parameters to adjust:

- `metal_detection_cutoff` (in both `MDT.ini` and `MDT_util.ini`): Adjust this to be less than the HU of the metal causing streaks, but higher than the highest bone HU. If the metal HU is lower than the highest bone HU, then the metal pixels will need to be manually set to a larger HU.
- `max_slice_thickness` (`MDT_util.ini`): The slice thickness should be thinner than the size of the implants, so that the metal HU is not reduced by partial volume effects.
- `MDT_ray_range` (`MDT.ini`): increasing this decreases streaks but also decreases the resolution around metal.

- `MDT_blur_diff_near_metal` and `MDT_blur_diff_far_from_metal` (`MDT.ini`): Increasing this decreases streaks present in the original image, but can result in new streaks between metal and high density non-metallic materials such as bone.
- `MDT_resolution_multiplier` (`MDT.ini`): Changing this from 1 to 2 possibly improves image quality, but is much slower.
- `MDT_iterations` (`MDT.ini`): The optimal number of iterations can be different for different images.

Key references

1. Boas FE and Fleischmann D. (2011) "Evaluation of two iterative techniques for reducing metal artifacts in computed tomography." *Radiology*. 259(3): 894-902.
2. Golden C, Mazin SR, Boas FE, Tye G, Ghanouni P, Gold G, Sofilos M, Pelc NJ. (2011) "A comparison of four algorithms for metal artifact reduction in CT imaging." *Proc. SPIE*. 7961: 79612Y.
3. Boas FE and Fleischmann D (2012). "CT artifacts: Causes and reduction techniques." *Imaging in Medicine*. 4(2): 229-40.
4. Boas FE. (2012) "Iterative reduction of artifacts in computed tomography images using forward projection and an edge-preserving blur filter." US patent 8233586.

Version history

The software version is recorded in the output DICOM file header (0018,1020,Software Version).

Version 1.1 (Released on 2013-04-26): Improved DICOM support and improved error handling.

Version 1.0 (Released on 2011-10-30): 6x faster than version 0.93, and decreased streaks, especially for intracranial aneurysm coils.

Version 0.93 (Released on 2011-06-29): DICOM send and receive interface, for integration with PACS.

Version 0.9 (Released on 2010-11-29): Initial public release on www.revisionrads.com, announced at RSNA.

Contact information

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Revision Radiology: <http://www.revisionrads.com>