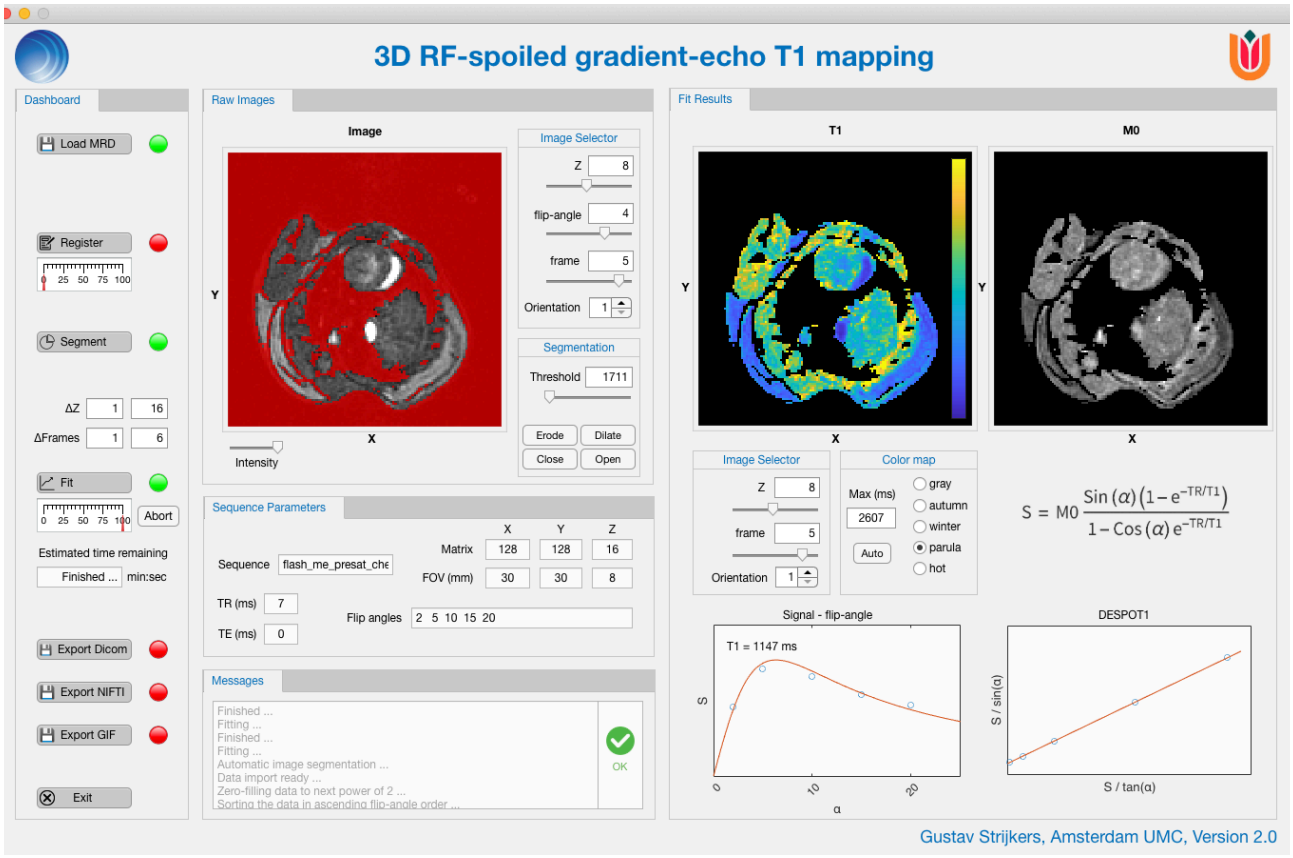

Table of contents

1. Overview

T1map is a software utility and graphical user interface to generate quantitative T1 maps using the variable flip angle method. The variable flip angle method derives a T1 map from a 3D RF-spoiled gradient-echo data set, acquired with variable flip angle α.

2. Contact

T1map and this manual is written by:

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3. Disclaimer

The software has been extensively tested using mouse data acquired with an MR Solutions preclinical 7.0T/24cm system.

However, this does not warrant the functions contained in the program will meet your requirements or that the operation of the program will be uninterrupted or error-free.

In case of questions or issues, please contact Gustav Strijkers.

4. Use of T1map

T1map is free of use. However, referencing the maker of *T1map* in scientific publications is highly appreciated.

5. Installation notes

Software download

Matlab source code and a Windows standalone version (using the free Matlab runtime engine) can be downloaded from GitHub:

`https://github.com/Moby1971?tab=repositories`

Installation of the Windows standalone version

`MyAppInstaller_web.exe`

Will install the Matlab runtime engine and the *T1map* program.

Bart toolbox download

Currently, T1map does not require the BART toolbox. Future advanced (model-based) reconstruction options may need BART, which can be downloaded from:

`https://mrirecon.github.io/bart/`

Bart toolbox installation in OSX

(1) Install Xcode from the Mac App Store

(2) Install MacPorts (`http://www.macports.org/`)
It is recommended to install a newer version of gcc from MacPorts

(3) Installation

```
$ xcode-select --install
$ sudo port install fftw-3-single
$ sudo port install gcc6  (or newer, also change version in Makefile)
$ sudo port install libpng
$ sudo port install openblas
$ make all clean
$ make
```

Bart toolbox installation in Windows 10

(1) Install the Windows subsystem for Linux

Start a windows powershell and run the following command:

```
Enable-WindowsOptionalFeature -Online -FeatureName Microsoft-Windows-Subsystem-Linux
```

A system restart will be needed.

For more information, see:

```
https://docs.microsoft.com/en-us/windows/wsl/install-win10
```

(2) Download Ubuntu Linux 18.04

For more information see:

```
https://docs.microsoft.com/en-us/windows/wsl/install-manual
```

Install the `appx` file by double-clicking in Explorer or in a PowerShell command prompt:

```
Add-AppxPackage .\app_name.appx
```

You will be asked to create a user account the first time you start a Linux command prompt.

(3) Upgrade the Linux distribution

```
$ sudo apt-get update
$ sudo apt-get dist-upgrade
```

(4) Install Bart prerequisites

```
$ sudo apt-get install make gcc libfftw3-dev liblapacke-dev
  libpng-dev libopenblas-dev gfortran
```

(5) Download Bart

```
$ wget https://github.com/mrirecon/bart/archive/v0.7.00.tar.gz
```

For WSL1 version 0.4.02 is recommended. Newer versions seem to compile but some functions which are required produce errors. Upgrade to WSL2 for higher versions (see e.g. https://pureinfotech.com/install-windows-subsystem-linux-2-windows-10/ on how to upgrade).

(6) Build Bart

```
$ tar xvfz v0.7.00.tar.gz
$ cd bart-0.7.00
$ make
$ make utest
$ make test
$ sudo make PREFIX=/usr/local install
```

6. Running the software

Running in Matlab 2021a

The Retrospective software can be started from its root directory from the command line.

```
>> T1map
```

Notes:

(1) The Retrospective root directory `~/T1mapping-3D` contains the following text file:

`bartpath.txt`	Bart toolbox installation directory Delete this file if the Bart toolbox is not available on your system Make sure that the text file contains exactly 1 line of text

(2) Additional licenses may be required.

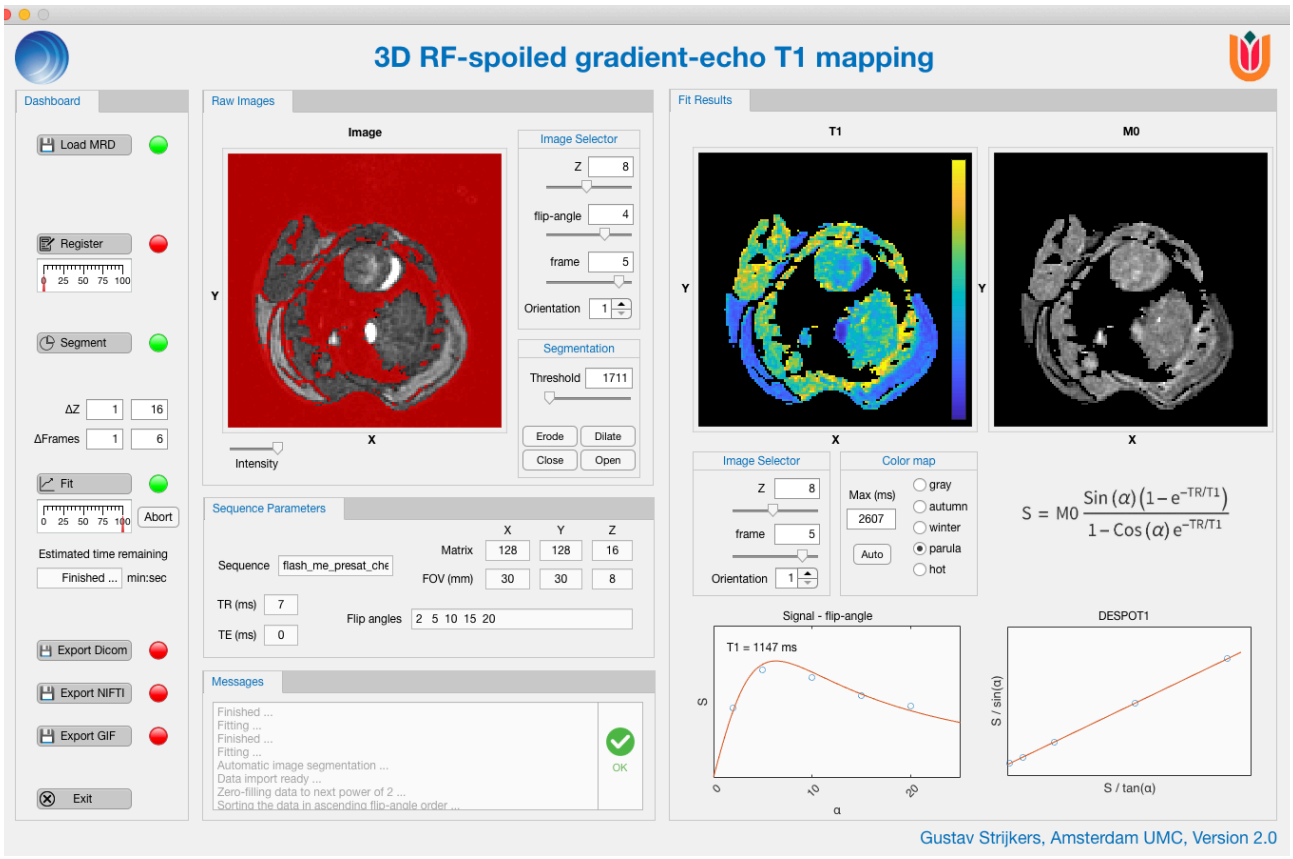
```
>> license('inuse')
communication_toolbox
distrib_computing_toolbox
image_toolbox
matlab
```

Running the Windows standalone

The Windows standalone version can be run from the start menu or the desktop icon.

7. Basic operation

The *T1map* program operates from a single window with 5 main panels.



Panel 1: Dashboard

This panel contains the task buttons that control the T1 mapping process. The dashboard tasks generally need to be completed from top to bottom. A green light next to the task indicates that the task has been completed. When the light is yellow the task is busy. Red indicates not completed yet.

Panel 2: Raw Images

Displays the raw images with variable flip angle.

Panel 3: Sequence Parameters

Lists some relevant sequence parameters.

Panel 4: Messages

Reports on the state of the program and displays error messages.

Panel 5: Fit results

In this panel the reconstructed T1 maps and M0 maps are shown.

Step 1: Loading data

Press Load MRD to import load the MRD raw data file.

Static 3D data:

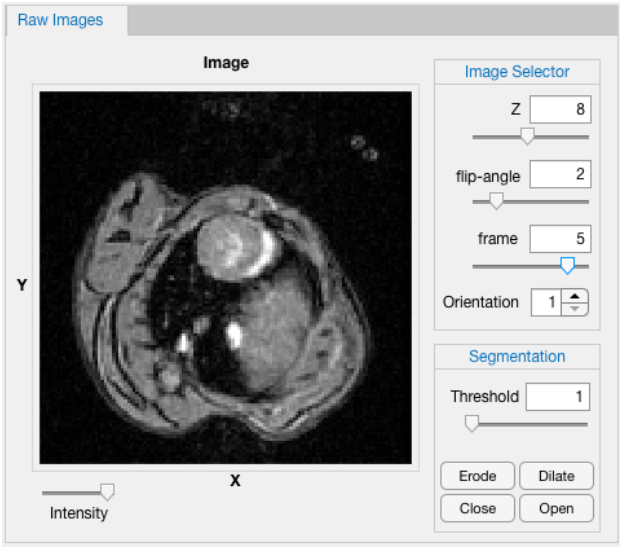
The data should be acquired with a 3D gradient echo sequence with RF spoiling with variable flip angle. A set of typical flip angles would be: 2°, 5°, 10°, 15°, 20°.

Cardiac T1 mapping:

Cardiac T1 mapping can be done by acquiring 3D retrospectively gated CINE images with variable flip angle. Reconstructions of the 3D CINEs with variable flip angle can be done using the *Retrospective* app (version 8, available on GitHub). In *Retrospective* export the images as MRD file. This MRD file can subsequently be loaded in the *T1map* app.

Step 2: Inspecting the raw data

In panel 2 the raw data as function of flip angle and — in case of cardiac data — as function of cardiac frame can be displayed.



Use the sliders to vary slice, flip-angle, and frame numbers, or edit the values. Also, the mouse scroll wheel will increase/decrease the slice number.

The orientation of the 3D dataset can be change by toggling the Orientation button.

Step 3: Image registration

In case there is considerable movement between the variable flip angle acquisitions one can perform a basic rigid image registration. Start the registration with Register .

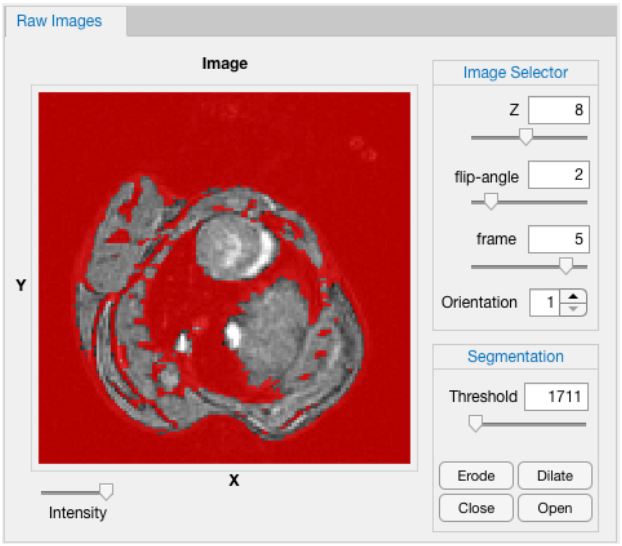
Registration is usually not needed and therefore this step can be skipped.

Step 4: Image segmentation

To mask background pixels in the fitting process and T1 maps, a basic image segmentation based on a signal threshold is performed.

To start the segmentation process, press Segment .

The resulting segmentation mask will be overlaid in red in the images as shown below.



The mask can be fine-tuned by manually changing the Threshold value or by applying morphological operations (erode, dilate, close, and open).

Step 5: Fitting the T1 maps

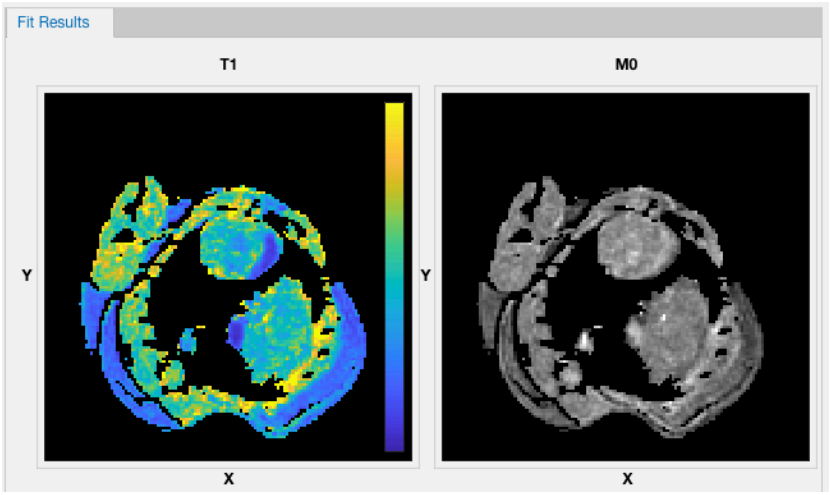
Fitting of the T1 maps is started by pressing Fit .

For testing and to reduce fitting time one can select the range of slices and frames for fitting.

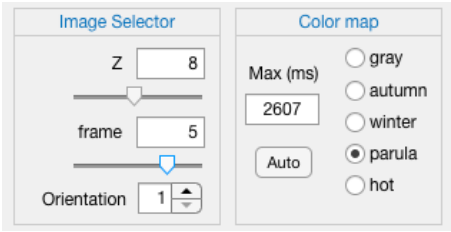
However, total fitting time of even large 3D datasets is fast. For example, total fitting time for the here presented dataset (128 x 128 x 16 pixels and 6 cardiac frames) was approximately 10 seconds.

Step 6: Inspecting the T1 maps

The resulting T1 maps and M0 maps are shown in the Fit Results panel.



Use the sliders to vary slices and frame numbers, or edit the values. Also, the mouse scroll wheel will increase/decrease the slice number. The T1 scale is from [0 to Max (ms)] and can be manually or automatically adjusted. Different colormaps can be chosen.



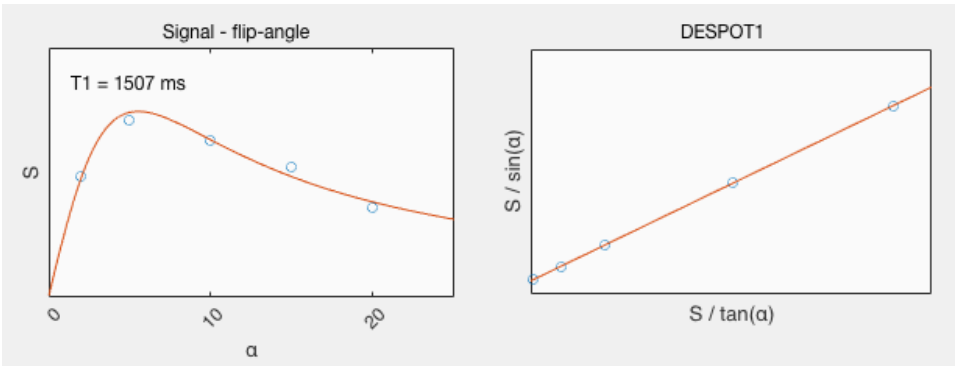
T1 fitting is done by a least-squares optimization of the signal equation on the right, after linearization by the so-called DESPOT1 method.

$$S = M0\,\frac{\mathrm{Sin}(\alpha)\left(1-e^{-TR/T1}\right)}{1-\mathrm{Cos}(\alpha)\,e^{-TR/T1}}$$

For more information, see:

(1) Deoni et al., Magn Reson Med 53, 237–241 (2005).

(2) Coolen et al,, NMR Biomed 24, 154–162 (2011).



Mouse click on individual pixels in the T1 map to inspect single pixel fits of T1. Open circles are the variable flip angle data points and the solid red line is the fit. Plot on the left shows the raw signal S as function of flip angle α, whereas the plot on the right shows the linearized representation by the DESPOT1 method.

Step 7: T1 map export

There are several ways to export the T1 maps.

(1) **Export Dicom**

Exports the data in Dicom format for further processing in 3rd party software. The program searches for the Dicom information. If this information is not found, tags will be generated by the program itself. In the latter case the correct image position and orientation information are lost.

(2) **Export NIFTI**

Exports 3D and 3D-time CINE in NIFTI format for further processing in 3rd party software.

(3) **Export GIF**

Generates animated-gifs of the T1 maps.

Step 8: Exit

Press 

to shut down the program.