Name of your team: Shimming Toolbox

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Shimming Toolbox GitHub repository: https://github.com/shimming-toolbox/shimming-toolbox

Website: https://shimming-toolbox.org

Shimming Toolbox: Making Advanced MRI Shimming Techniques Accessible to Everyone

Context

In a quest for higher signal-to-noise ratio (SNR), MRI manufacturers have kept increasing the main magnetic field strength (B0 field). However, an important problem that arises at higher field strength is increased inhomogeneity of the static (B0) and RF transmit (B1+) fields [1]. These inhomogeneities can cause distortions in the images [2], signal loss, and other undesirable image artifacts [3]-[4].

To minimize these effects, it is essential to ensure the spatial uniformity of the B0 and B1+ field by homogenizing it, also known as shimming. Active B0 shimming involves driving currents through multiple coils to generate magnetic fields that counteract the inhomogeneities. A multitude of techniques have been proposed in the past, including static B0 shimming, which optimizes the B0 field in a single region; dynamic B0 shimming, which optimizes multiple regions independently; real-time B0 shimming, which aims to compensate for homogeneities that can occur over time, such as inhomogeneities caused by the respiration of the patient. However, only static B0 shimming is usually available on scanners and is not sufficient to properly shim the B0 field. Similarly, B1+ shimming is limited in vendor solutions in that the region of interest is often limited to a simple rectangular box, whereas in some situations, a more complex geometry would be desirable (eg: spinal cord). Researchers requiring advanced shimming solutions need to reimplement the techniques themselves, which is time-consuming, requires expertise, and is error-prone leading to poor reproducibility of research results.

Shimming Toolbox

Goals

In this context, we have developed *Shimming Toolbox* (https://shimming-toolbox.org), an open-source software package for prototyping new methods and performing static, dynamic and real-time B0 shimming experiments as well as static B1+ shimming experiments. *Shimming Toolbox* [5] provides a platform where researchers can

collaborate, prototype, conveniently test B0 and B1+ shimming experiments, and contribute to new shimming methods and novel MRI technologies that are transparent and reproducible.

Features

Shimming Toolbox (https://shimming-toolbox.org) provides a range of features that can be accessed through an intuitive graphical user interface (GUI) as a plugin in the popular MRI imaging viewer FSLeyes [6] and through the command line. It can be installed on a computer, used on already acquired data, or connected to the MRI scanner during an imaging experiment. The toolbox can convert images into an open-science format (NIfTI files with an associated brain imaging data structure (BIDS) [7], [8] metadata file), create B0 maps of the field useful for shimming, characterize shim coils, create masks, perform B0 and B1+ shimming, and more. A website is also available which includes installation instructions, documentation, and tutorials showing how to use *Shimming Toolbox*.

Shimming Toolbox is written in Python and relies on open-source packages such as dcm2niix [9], dcm2bids [10] and Spinal Cord Toolbox (SCT) [11]. The code is public on GitHub at this link https://github.com/shimming-toolbox/shimming-toolbox and we encourage outside collaborators to request features and implement their shimming algorithms.

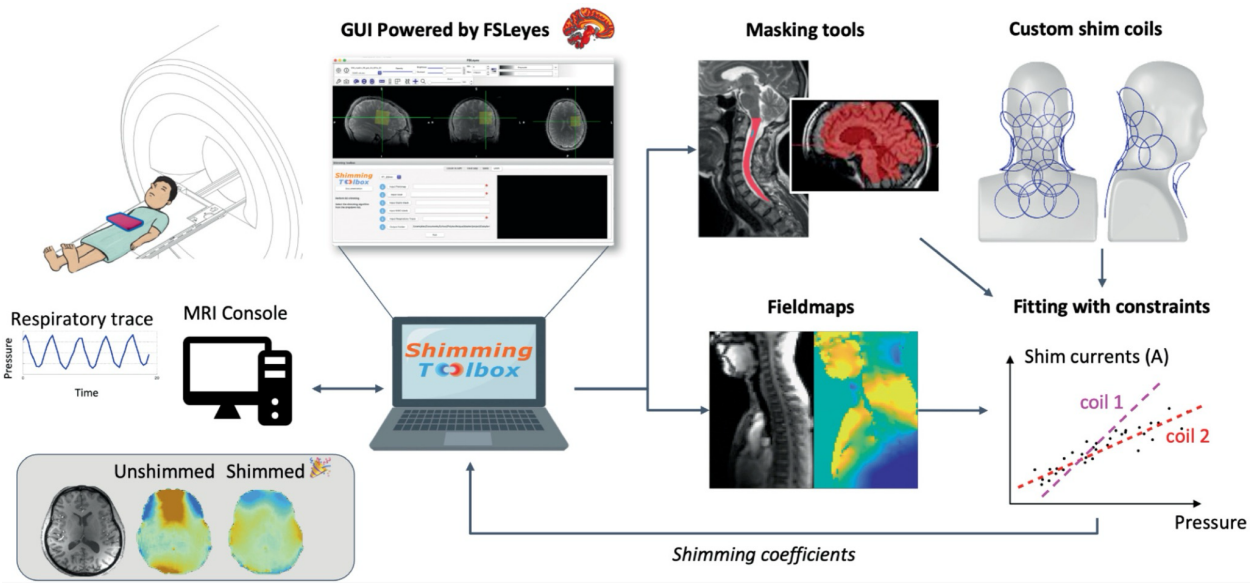

Figure 1: Overview of *Shimming Toolbox*.

Shimming Toolbox was officially announced on November 28th, 2022 and has been used and tested in multiple experiments. The following figure shows brain images and B0 field maps that demonstrate the shimming capabilities of the scanner and compare them to those of the *Shimming Toolbox*. A more detailed explanation as well as other experiments (B1+ and B0 real-time shimming) can be found in the publication at this link: https://onlinelibrary.wiley.com/doi/10.1002/mrm.29528.

Since its launch, we have received inquiries from users and external contributors who are currently performing experiments with the software.

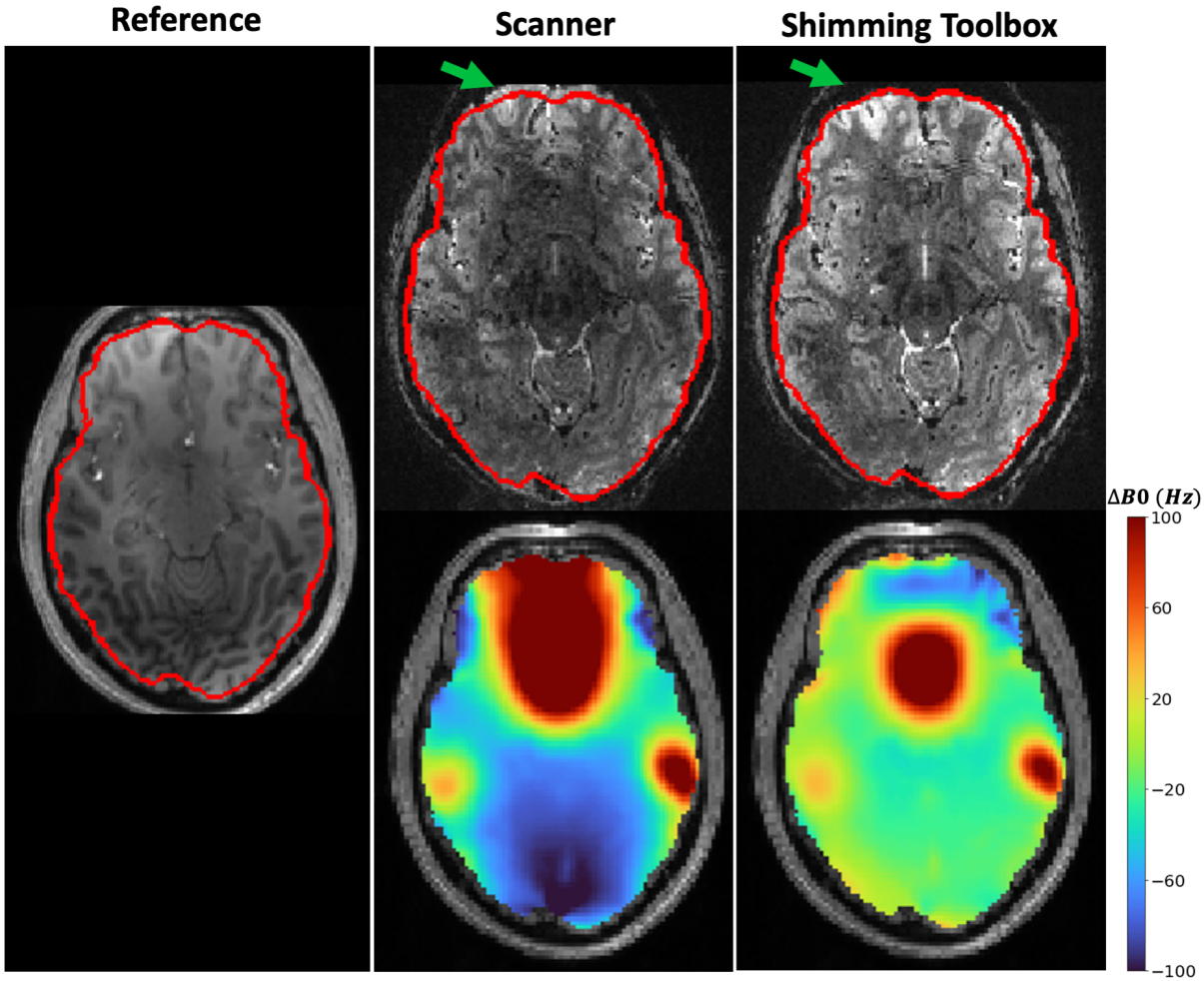

Figure 2: A non-distorted reference scan (Reference) was acquired and the brain was segmented (red contour) and shown on all acquired images. The right two columns show brain images (top) acquired using an echo planar imaging sequence susceptible to distortions and signal loss due to B0 field inhomogeneities, and B0 field maps (bottom) to compare shimming optimized by the scanner (Scanner) and scans acquired while using *Shimming Toolbox* to perform shimming calculations (Shimming Toolbox).

Impact and collaboration

Although *Shimming Toolbox* was recently introduced, it already has 21 stars on GitHub and 23 different contributors. We are actively collaborating with other research groups to further the development and testing of shimming methods. For example, with Dr. Falk Eippert (Max Planck Institute, Leipzig Germany), we implemented the “Slice-wise z-shimming for spinal cord fMRI with Shimming Toolbox”, which was presented at the International Society for Magnetic Resonance in Medicine’s (ISMRM) annual 2023 meeting. With Dr. Jason Stockmann (Harvard/MGH Martinos Center, USA) we are developing shimming methods for a special type of radiofrequency coils on Siemens (a manuscript is underway). With Dr. Ken Weber (Stanford, USA) we are expanding the *Shimming Toolbox* to work on GE scanners. With Dr. Christoph Aigner (Physikalisch-Technische Bundesanstalt, Berlin Germany) we are developing whole-spine shimming methods at 7 Tesla that could be applied across the adult population without the need for long calibration, leading to faster MRI exams (a paper is under 2nd revision). Our group has also implemented support for MR spectroscopy (a manuscript is also underway). We are continuing to make *Shimming Toolbox* better and more reliable with frequent updates with new patches and features. Moreover, we are collaborating with Philips and the Centre Hospitalier Universitaire Sainte-Justine in Montreal to continue developing *Shimming Toolbox* and include it directly on Philips scanners. This has led to Philips users, notably from John Hopkins’ to use the toolbox. We were also approached by GE, another major MRI manufacturer after we demonstrated *Shimming Toolbox* at a high-field workshop in Lisbon, Portugal. By supporting all major vendors, it is our goal to make the toolbox a central location for the open-science shimming community. This will provide a platform for upcoming researchers and under-privileged labs to contribute to state-of-the-art shimming methods.

Originality

The shimming methods provided by most MRI manufacturers are very simple and do not meet the user’s needs, especially at higher fields. Their source code is usually not available to the public, making it difficult to improve their solutions and hampering the standardization and transparency of shimming methods. While some freely available toolboxes exist for B0 shimming (B0 Detox [12], Harmonized [13]) and B1 shimming (Parallel Transmission RF Shimming GUI[14] , Cardiac RF Shimming [15]), to the best of our knowledge, there is no open-source all-in-one software that can accommodate a variety of B0 and B1+ shimming experiments. *Shimming Toolbox* challenges the status quo by providing, improving, and developing advanced B0 as well as B1+ shimming solutions. Although other shimming tools exist, none of them provide the range of features, the extensive educational support (website) as well as support for most major MRI manufacturers while being actively maintained. *Shimming Toolbox* has gained

traction which has allowed the tool to be tested in a variety of scenarios making it more reliable.

Conclusion

Shimming Toolbox is an open-source software platform for MRI researchers to collaborate, prototype and conveniently test B0 and B1+ shimming experiments. The toolbox both uses and promotes open-science practices and encourages outside collaborators to request features and implement their shimming techniques.

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