How to Print Your Marker: an Open-Source, Easy-to-Make, Compact Active Wireless Marker for Motion Tracking

Alfredo De Goyeneche[1], Julian Maravilla[1], Karthik Gopalan[1], Abigail Falk[1], Stella Yu[1,2], Chunlei Liu[1,3], and Michael Lustig[1]
[1]*Electrical Engineering and Computer Sciences, UC Berkeley, Berkeley, CA, United States,* [2]*Computer Science and Engineering, University of Michigan, Ann Arbor, MI, United States,* [3]*Helen Wills Neuroscience Institute, UC Berkeley, Berkeley, CA, United States*

Synopsis

Keywords: Motion Correction, Motion Correction

Motivation: Accurate localization within MRI is critical for compensating for motion and tracking devices in the MRI environment.

Goal(s): We aim to improve upon previous fiducial marker designs by developing a compact, wireless open source design marker that simplifies construction and enhances usability for fast localization.

Approach: Our 3D-printed marker integrates a miniature RF coil, capacitor, and crossed diodes, designed for inductive coupling with the imaging coil, facilitating enhanced received signal direct connections to the scanner.

Results: We report the marker's tracking accuracy and artifact behavior in various imaging sequences, suggesting its potential utility in applications like robotic device tracking.

Impact: We introduce a compact, open-source 3D-printed wireless marker for localization applications, such as bulk motion tracking or external device tracking. We hope that the ease of construction and reproducibility will help facilitate its adoption by researchers and in clinical applications.

Introduction

Localization within MRI is essential for accurate imaging, particularly in prospective motion correction and for tracking elements such as robotic devices. Fiducial markers provide reliable reference points, supporting both motion correction and device monitoring; however, their signal might not be strong enough. Past research has developed various RF coil marker designs to aid in localization[1]; however, these require coaxial cables to connect to the scanner, which can interfere with clinical workflows, limiting the markers' practicality for broader use. Alternatively, wireless RF coils eliminate the need for cables through inductive coupling with the imaging coil[2]. Building on this, we designed a compact, 3D-printed version of the active fiducial that is simple to construct, smaller than $11mm \times 7mm \times 6mm$. We share our CAD model with the community (https://github.com/mikgroup/print_your_marker) to enable easy adoption and practical use.

Methods

Fabrication

The wireless marker circuit[2] consists of a miniature RF coil, a capacitor, and crossed diodes (model) that passively detune the resonant circuit during RF transmit (Figure 1a). The marker couples inductively to the receiver coil(s). It is localized by a sequence consisting of a non-selective RF pulse, gradient echo readouts, and perpendicular gradients to dephase the magnetization of large volumes, obtaining XYZ projections in $< 20ms$. The locations of multiple markers can be determined through geometry constraints[2] or via additional projection scans.
Our 3D-printed design (Figure 1c), created using Autodesk Fusion 360, builds on this approach with a simple construction process and reduces the marker's size. The model comprises two pieces with a central 3mm diameter spherical cavity filled with Gd-doped water solution, which serves as the tracking point source. The design includes a compartment to hold the capacitor (form factor $.110" \times .110"$), the diodes, and an extra slot for an optional capacitor to allow for finer frequency tuning. Figure 2 outlines the steps to build a marker:

1. **Coil the wire:** Loop the wire along the groove around the spherical cavity on the base piece.
2. **Assemble:** Place the capacitor on the base piece and the crossed diodes on the cap piece.
3. **Close & Solder:** Fit the cap onto the base and solder each side.
4. **Tune:** Using a Vector Network Analyzer (VNA), adjust the spacing between coil turns to tune the marker to the desired frequency.
5. **Fill & Seal:** Fill the cavity with Gd-doped water solution through the top hole and seal it.

When constructing your first marker, soldering everything without the cap can help find the appropriate capacitance value for the target frequency.

Experiments

We created markers tuned to 127.7 MHz for our 3T GE MR750w MRI. The markers were 3D printed using a FormLabs 3 printer with clear resin. We used an enamel-insulated wire, MA4P7446F diodes, and a 39 pF capacitor. Finally, we used 10nmol Gd-doped water, targeting a T1/T2 relaxation time of approximately 5 ms. The projection acquisition sequence was implemented with RTHawk (Vista.ai, Palo Alto, CA.)

We performed three acquisitions with different setups. First, we placed a ball phantom with a marker and obtained a 2D GRE scan and a projection acquisition. Next, four markers were placed at different orientations, and 3D SPGR and projection acquisitions were performed.

To test the accuracy of the obtained positions, we set the phantom to move using GE's rocker tool, rocking by 50mm. We also placed our marker on a printed grid at various positions and orientations, showing the obtained positions for each configuration (Figure 5b).

Results

Figure 3 shows the sensitivity of markers to placement and orientation. When the marker is placed with a ball phantom, the marker signal peak is visible while the phantom signal is suppressed (Column 1). The second and third columns display 3D scan renderings and projections of the four markers, with varied orientations. The final column highlights one marker aligned with the B0 field, rendering it undetectable in both the scan and projections. Figure 4 shows B0 and B1 maps for the ball phantom and marker setup, as well as example sequences to illustrate potential artifacts.
Figure 5a illustrates the measured trajectory of a marker during movement with the rocker. The tracked marker position is accurate as long as the markers are not aligned with B0.

Discussion and Conclusion

We introduce a compact, 3D-printed wireless marker designed for easy construction and reproducibility. We presented experiments to report its accuracy, including tests with varying orientations relative to the main magnetic field and traditional imaging sequences. While artifacts may appear, marker parameters (e.g., Gd concentration to adjust T1/T2 values) could be modified to suit each application. We hope this design provides a useful, accessible tool for the community.

Acknowledgements

We would like to acknowledge funding from R01MH127104 and GE Healthcare.

References

1. Ooi MB, Krueger S, Thomas WJ, Swaminathan SV, Brown TR. Prospective real-time correction for arbitrary head motion using active markers. Magn Reson Med. 2009;62(4):943–954. doi: 10.1002/mrm.22082
2. Ooi MB, Aksoy M, Maclaren J, Watkins RD, Bammer R. Prospective motion correction using inductively coupled wireless RF coils. Magn Reson Med. 2013 Sep;70(3):639-47. doi: 10.1002/mrm.24845. Epub 2013 Jun 27. PMID: 23813444; PMCID: PMC4006309.
3. Ackerman JL, Offutt MC, Buxton RB, Brady TJ. Rapid 3D Tracking of Small RF Coils. Proceedings of the 5th Annual Meeting of SMRM; Montreal, QC, Canada. 1986. pp. 1131–1132
4. Qin L, Schmidt EJ, Tse ZT, Santos J, Hoge WS, Tempany-Afdhal C, Butts-Pauly K, Dumoulin CL. Prospective motion correction using tracking coils. Magn Reson Med. 2013;69(3):749–759. doi: 10.1002/mrm.24310

Figures

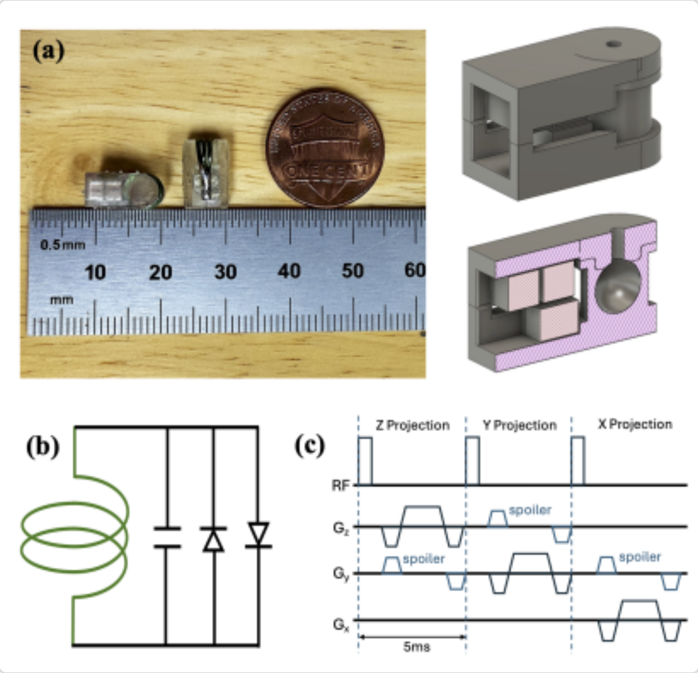

Figure 1. (a) Shows our 3D-printed open-source marker design (<11x7x6 mm), featuring a 3mm spherical cavity with Gd-doped solution as the tracking source. The compact model allows for frequency tuning and simple assembly. Model is available at https://github.com/mikgroup/print_your_marker. (b) The wireless marker circuit[2] includes an RF coil, capacitor, and diodes to passively detune the circuit during RF transmit, (c) localized by a projection sequence[2] (RF pulse, gradient echo readouts, perpendicular dephasing gradients) in <20 ms.

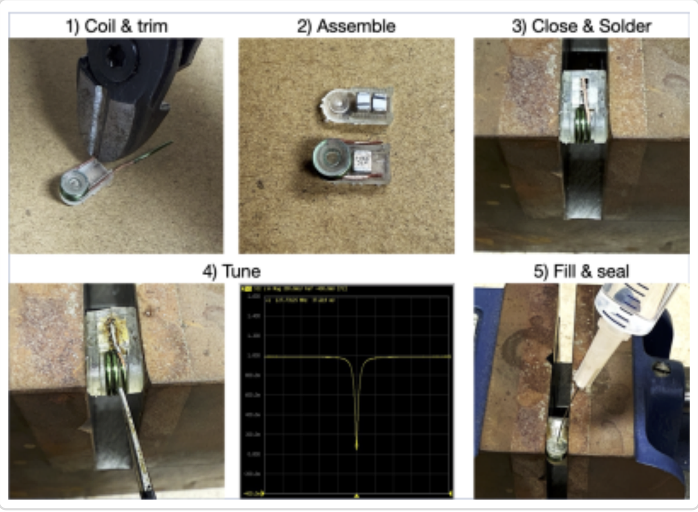

Figure 2. Step-by-step assembly of the 3D-printed wireless marker. (1) Coil three wire loops around the groove surrounding the spherical cavity on the base piece. (2) Place the capacitors and the crossed diodes on the printed pieces. (3) Secure the cap with a vise and solder the wire connections. (4) Finetune the marker's resonance frequency using a VNA by adjusting coil spacing. (5) Fill the cavity with Gd-doped water solution, then seal (e.g., UV-curable glue).

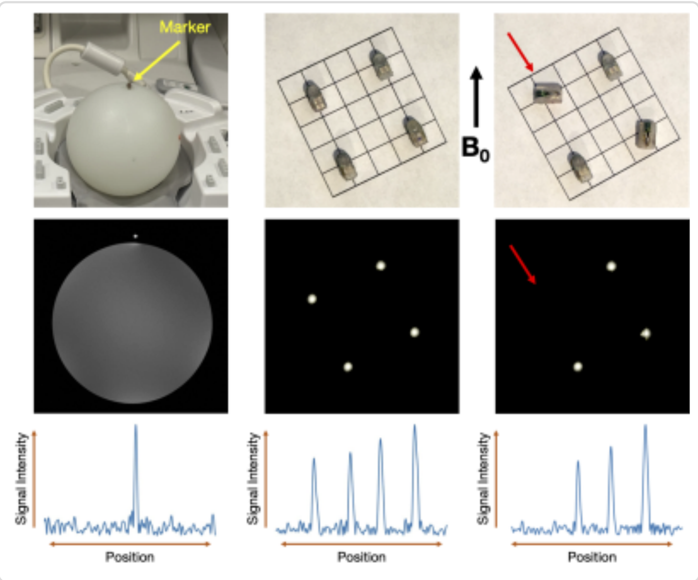

Figure 3. Acquisition and projection examples. The first column shows a ball phantom with a marker, a 2D GRE scan, and the corresponding projection acquisition, where the marker signal peak is visible and the phantom signal is suppressed. The second and third columns present four markers with different orientations, their 3D SPGR volume renderings, and corresponding projections. The last column shows one marker aligned with the B0 field, rendering it undetectable in both the scan and projections.

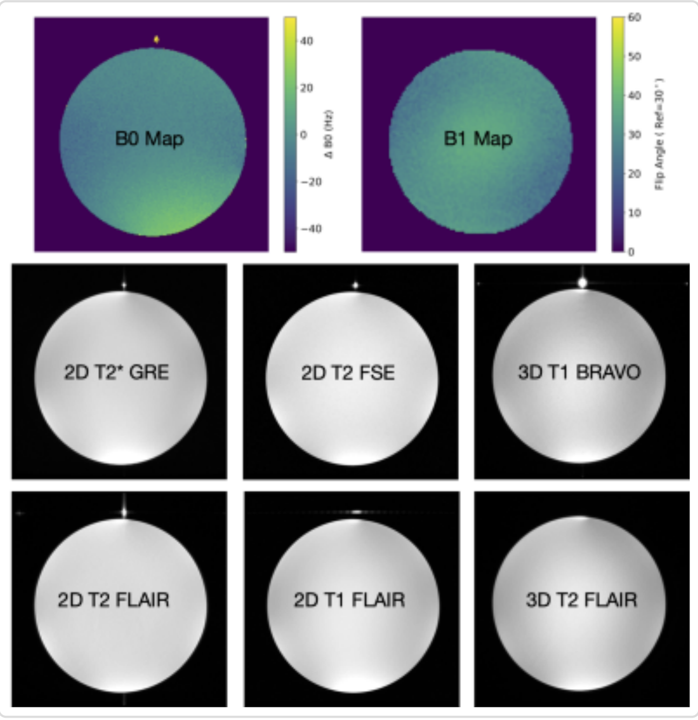

Figure 4: B0 and B1 maps of the ball and marker setup, along with various MR sequence scans that present artifacts introduced by the marker. While B0 and B1 maps show no noticeable impact, sequence scans display instances of marker signal spreading artifacts in the phase encode and/or readout directions. Adjusting marker characteristics, such as cavity size or T2 properties, to reduce signal intensity could mitigate these effects. Despite potential artifacts, marker parameters could be optimized for specific applications.

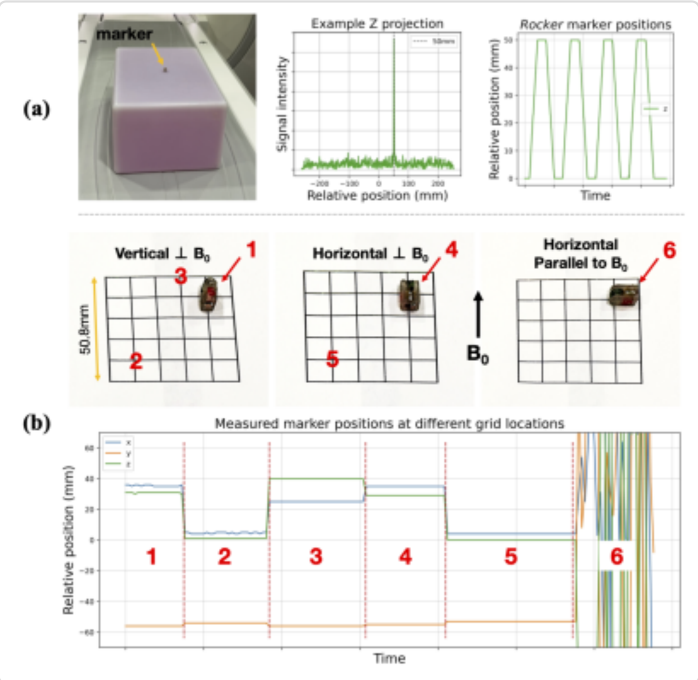

Figure 5: (a) Rocker experiment setup, showing a block phantom with a marker, an example projection acquisition, and the measured trajectory as the patient bed moves from 0 to 50 mm. The marker accurately tracks the motion range. (b) Marker placements at six different grid positions and orientations over the phantom, with corresponding position acquisitions. When the marker is aligned with B0, no signal from the marker is obtained and the position could not be determined.

DOI: https://doi.org/10.58530/2025/4589