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Binary-coded multiplexing acquisition for flexible receiver arrays in Magnetic Particle Imaging

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Abstract

Wearable Magnetic Particle Imaging (MPI) relies on dense arrays of small receiver coils to achieve flexible sensing, but increasing coil count rapidly raises DAQ channel requirements and system complexity. We propose a binary-coded, time-division multiplexed readout that sequentially addresses receiver coils and jointly encodes coil identity and discretized signal amplitude using rectification, thresholding, and logic decoding. The quantization level is configurable, and higher quantization improves reconstruction fidelity in our evaluations while maintaining a reduced channel requirement. This approach enables scalable, low-cost readout for dense, flexible MPI receiver arrays.

I. Introduction

Magnetic Particle Imaging (MPI) is a tracer-based imaging technique offering high sensitivity, zero tissue background, and quantitative detection. Conventional rigid receiver coils limit imaging of curved body regions, where coil–tissue distance increases toward the edges, degrading sensitivity. Flexible multi-coil arrays can conform to anatomical surfaces and improve coupling, but scaling up coil numbers drastically raises DAQ channel requirements.

Knopp et al. [1] introduced receive-coil arrays to enhance MPI sensitivity and coverage, Graeser et al. [2] optimized analog front-end design for stable low-noise reception, and Günther et al. [3] demonstrated a lightweight head-scanner concept highlighting the practical need for multi-coil, body-adaptive receiver structures. Building on these efforts, this work proposes a binary-coded multiplexing scheme that enables a large number of receiver coils to be addressed and read out through limited acquisition ports, achieving efficient spatial and signal-level encoding for scalable, flexible MPI systems.

II. Methods

As illustrated in Figure 1, a deterministic polling scheme is used to read out an M × M receiver-coil array under limited acquisition ports. All coils continuously sense the magnetic response, while a front-end addressing unit scans the array in a fixed order and selects one coil per

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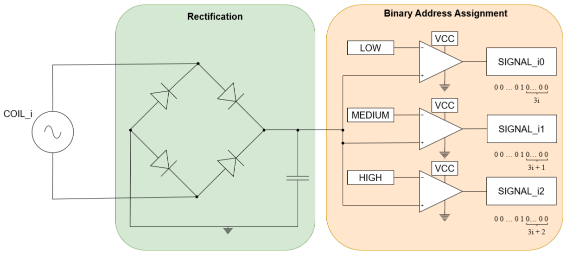

Figure 1: Polling-based rectification and N-level binary assignment. Receiver coils are polled sequentially; the addressed coil signal is rectified and compared with N thresholds to generate level-indicator outputs ($\mathrm{SIGNAL}_{i1}, \ldots, \mathrm{SIGNAL}_{iN}$) for subsequent encoding.

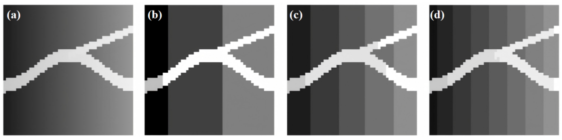

Figure 2: (a) Vessel phantom reference image. (b–d) Results with N = 10, 20, and 30, respectively.

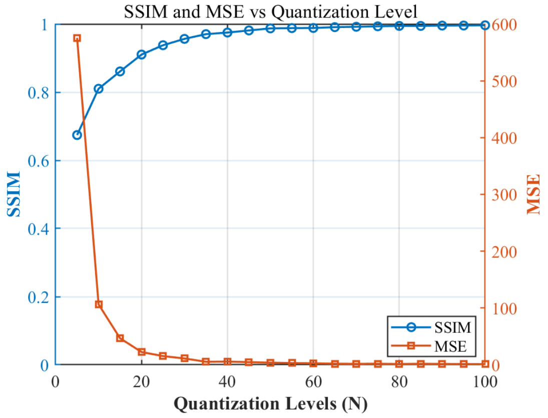

Figure 3: Image similarity and error metrics between the reconstructed images and the reference image versus quantization level N.

time slot, routing only the addressed coil signal to the downstream processing chain. The selected coil signal is full-wave rectified to form a non-negative envelope and compared against N preset thresholds, producing N binary level-indicator outputs ($\mathrm{SIGNAL}_{i1}, \ldots, \mathrm{SIGNAL}_{iN}$) that represent discretized amplitude classes. Over the full array, this corresponds to $M^2 \times N$ level-indicator lines, which are compressed by cascaded priority-encoding logic into a compact binary representation. The resulting output codes are mapped back to the corresponding coil position and amplitude level during reconstruction, enabling sequential acquisition frames without requiring a dedicated DAQ channel for each coil. The dwell time per slot is chosen to ensure stable analog routing and reliable readout while meeting the temporal resolution required by the MPS/MPI acquisition.

III. Results and discussion

Simulation studies were conducted to evaluate both the feasibility of the proposed polling-based, binary-coded readout and the impact of amplitude discretization on reconstruction fidelity. A vessel phantom was tested under different quantization levels: as shown in Figure 2, coarse quantization leads to visible banding in the background gradient and reduced structural continuity, whereas increasing N improves visual agreement with the reference. Figure 3 summarizes the corresponding quantitative trend, indicating improved image similarity and reduced error with higher N. These results confirm that the deterministic codes produced by time-division polling can be reliably mapped back to the coil index and amplitude level, and that the quantization-induced loss in amplitude precision can be mitigated by increasing N, offering a practical trade-off between channel reduction and reconstruction fidelity for dense, flexible receiver arrays.

IV. Conclusion

We presented a polling-based, binary-coded multiplexing readout for dense and flexible MPI receiver arrays. The method sequentially addresses coils and converts each coil's rectified signal into N-level amplitude indicators, which are further compressed into a compact binary representation for reduced-channel acquisition. Results on a vessel phantom and quantitative evaluations across different N demonstrate that increasing quantization levels improves reconstruction fidelity while maintaining the benefit of reduced acquisition channels. This approach provides a scalable and low-cost readout strategy for high-density receiver arrays.

Author's statement

Conflict of interest: none. Informed consent: not applicable. Ethical approval: not applicable.

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