



# Motion Tracking for Globally Controlled Self-Reconfigurable Magnetic Modular Cubes



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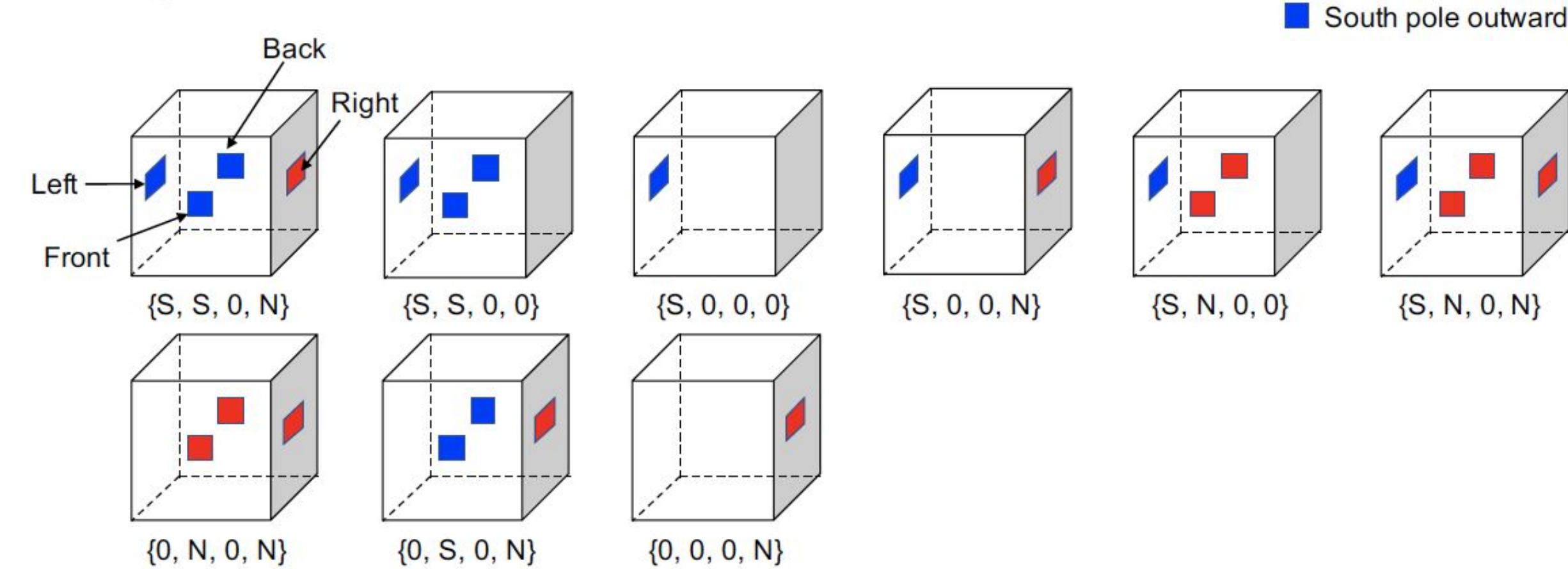
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## Background and Motivation

- **Reconfigurable modular robots** have garnered interest for their *reusability, variety of application, and adaptability* to environments.
- Previous models describing motion of modular robots cannot overcome **stochasticity** in **dynamic systems**.
- We seek to produce a *more robust* path planner and model for motion, assembly, and disassembly of our **magnetic modular cubes (MMCs)** [1], [2] with **motion tracking software**.

## 2D designs



2D MMC designs can produce a variety of structures [1, Fig. 1]. Designs {S,S,0,N} (blue-arrowed cubes) and {S,N,0,N} (red-arrowed cubes) were used.

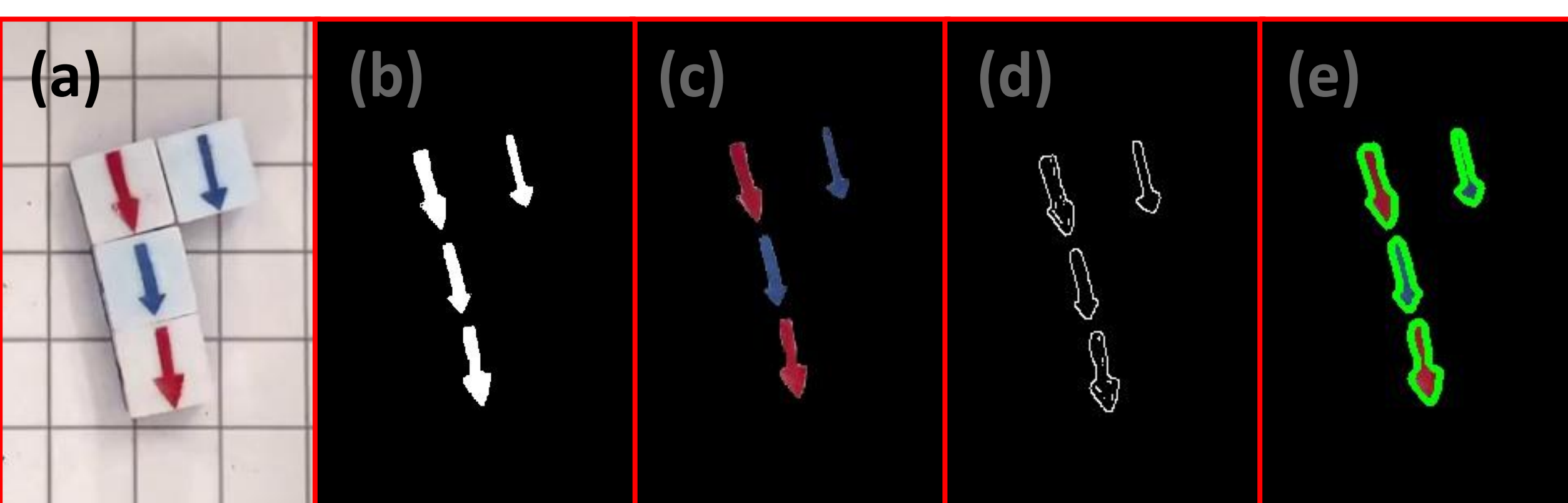
## Design and Approach

### Previous Work

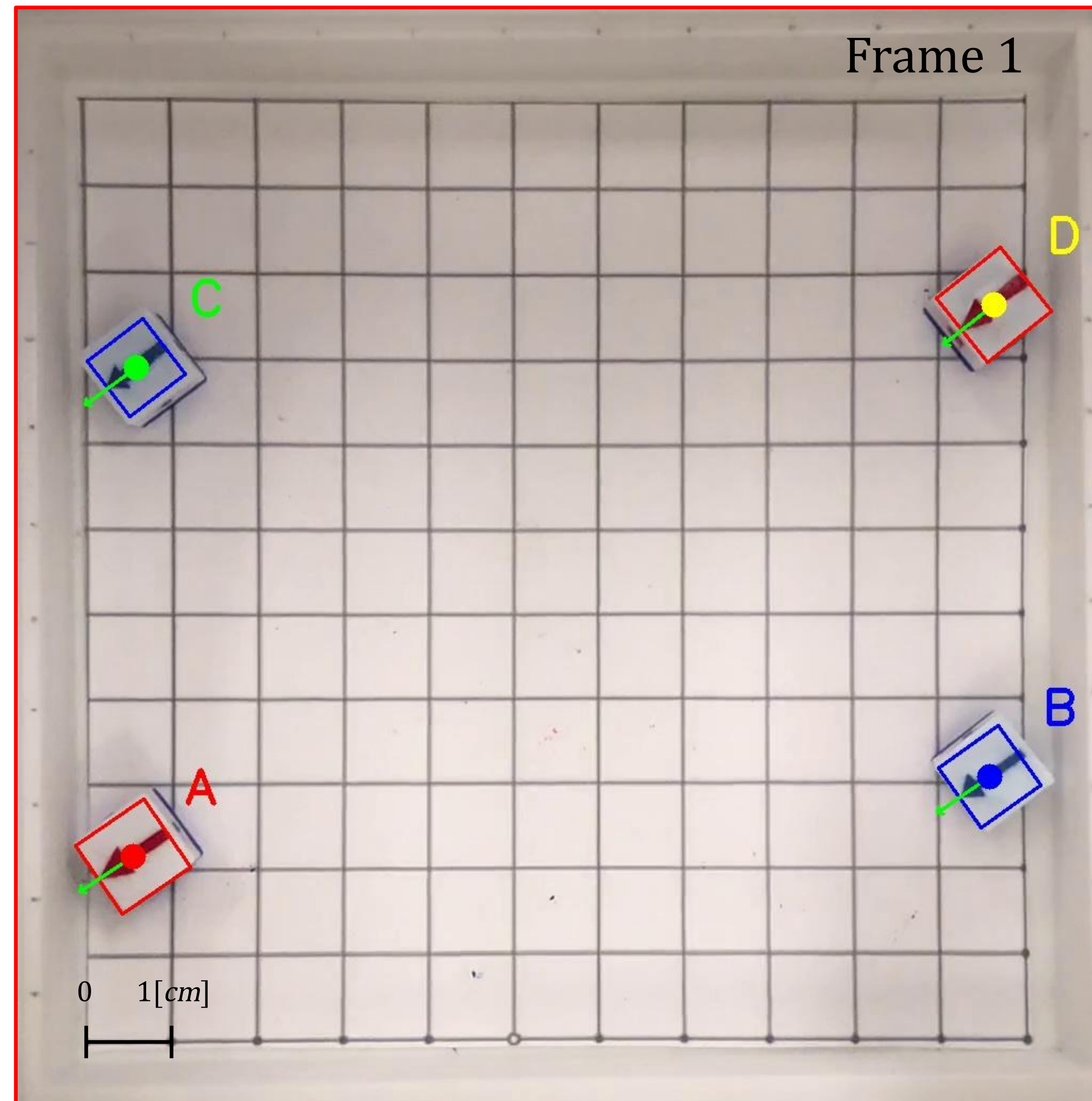
- MMCs sit on a bounded, flat workspace within a nested Helmholtz coil system that actuates MMCs with **global magnetic fields**.
- A C++ **path planner program** operates the coil system to move, assemble, and disassemble structures.

### New Contributions

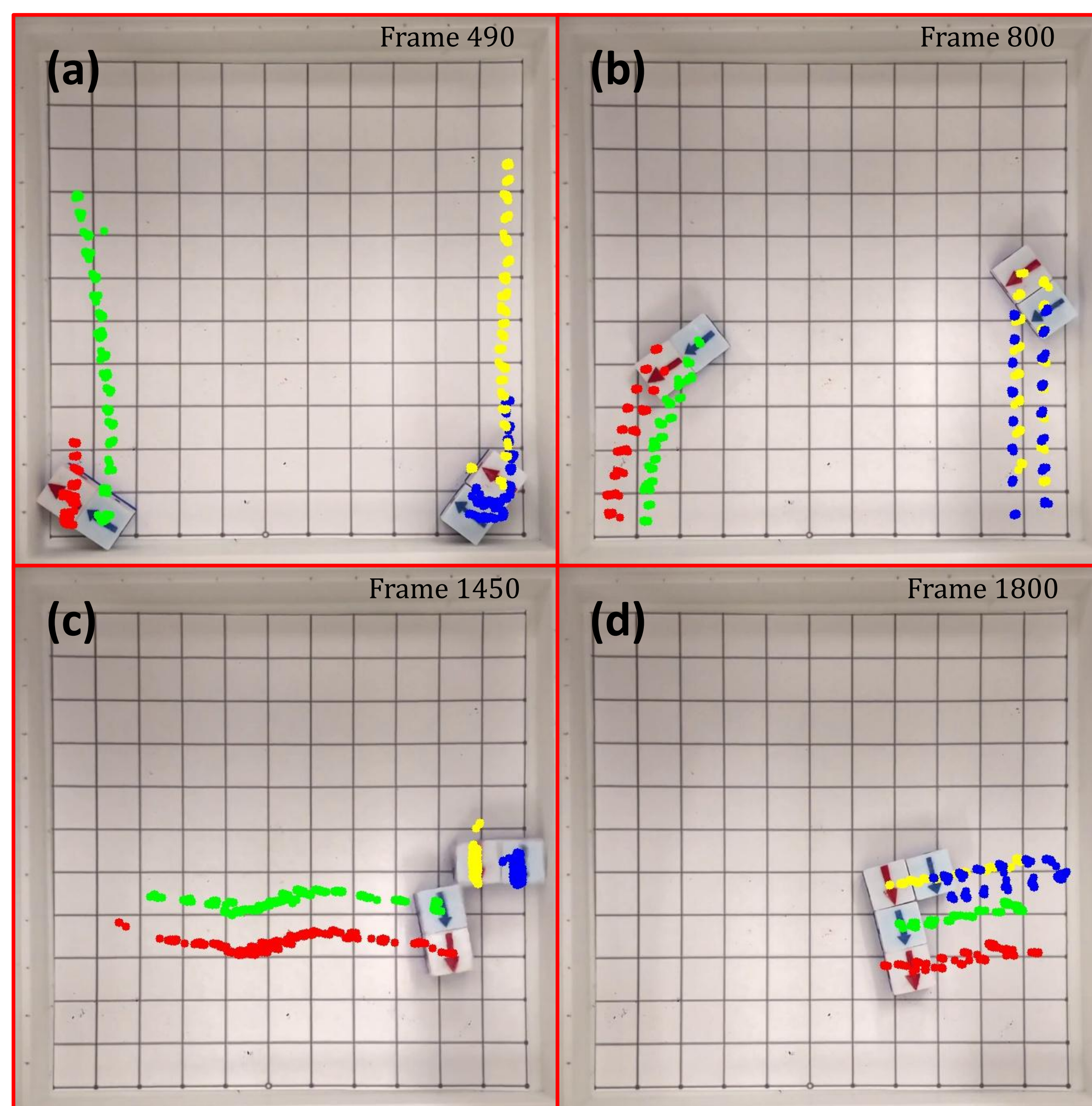
- Our **motion detection program** is written in Python and uses OpenCV for video and image processing.
- A **greedy algorithm** was designed to track each cube throughout the video using a Euclidean distance matrix.



Process of cube tracking: (a) Unaltered frame taken from video; (b) HSV thresholding isolates and binarizes arrow regions into a mask; (c) mask is used to extract colored arrows; (d) Canny edge detection generates contours; (e) contours contain all information required for motion tracking.



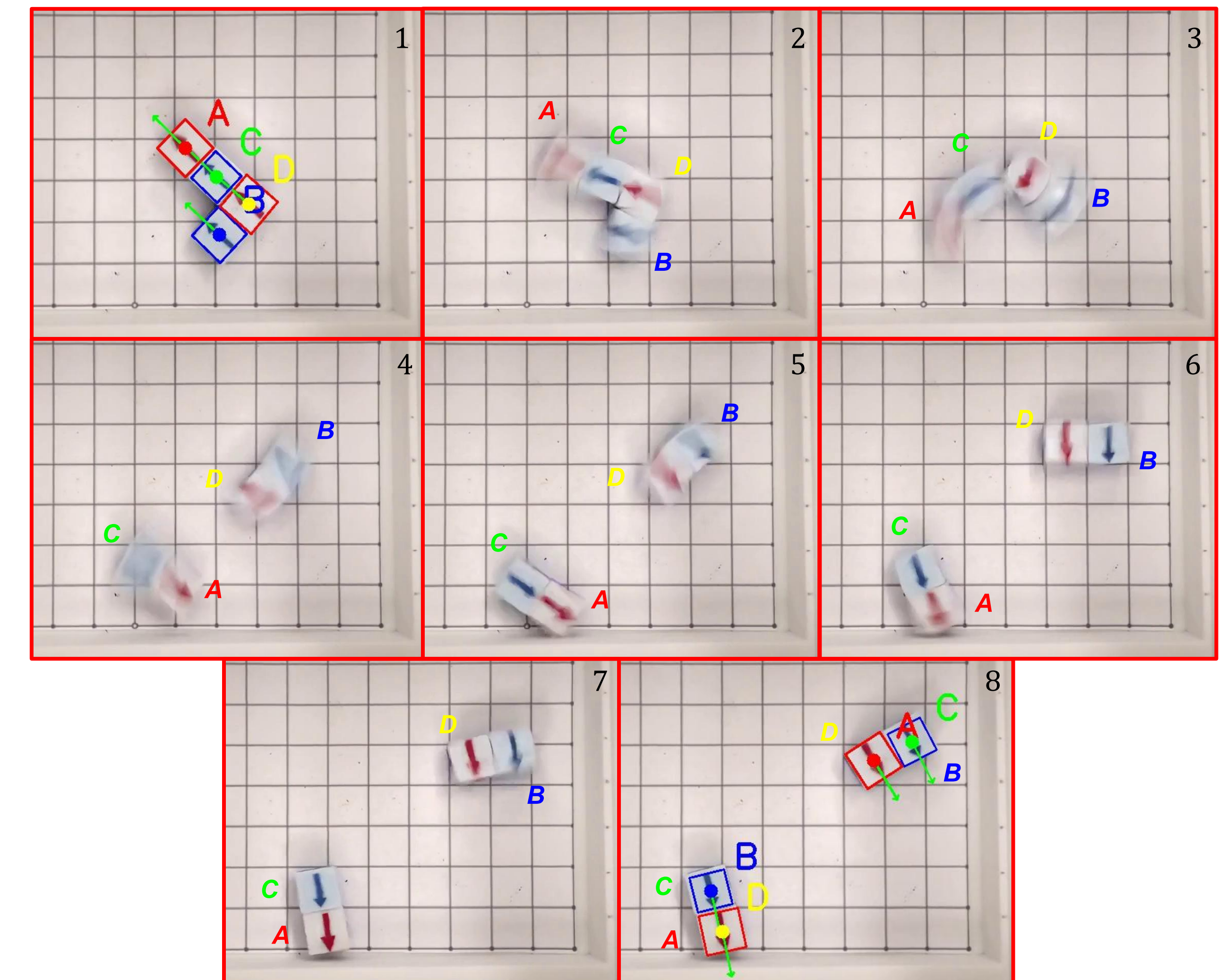
Each cube is assigned a unique label, and their colors, positions, and orientations are indicated.



Motion paths of MMCs: (a) Motion from initial position to first assembly event; (b) motion of coupled cubes; (c) motion to second assembly event; (d) motion of final structure.

## Results

- In video with smooth movements, **correct identification and tracking in 82% of frames** (1476 out of 1800).
- Samples featuring **rapid motion** produced **label swapping** between similar MMCs, exposing a limitation in the algorithm.



Instance of failure: Rapid motions distort video frames. The algorithm cannot correctly identify sets 2-7, and erroneously swaps the cube labels.

## Conclusion and Future Work

- Our algorithm performs well under smooth conditions, but **rapid motions tend to cause failures**. This might be fixed with better-quality cameras.
- Other techniques like the **Hungarian algorithm** and **optical flow** exist, which might lend to better matching results for cube tracking.
- Future versions of this program will be incorporated into our path planner for **real-time error checking** and **dynamic path adjustment**.

## References and Acknowledgements

- [1] Y. Lu, A. Bhattacharjee, D. Biediger, M. J. Kim, and A. T. Becker, "Enumeration of polyominoes & polycubes composed of magnetic cubes," in Proc. 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Prague, Czech Republic, Oct. 2021.
- [2] A. Bhattacharjee, Y. Lu, A. T. Becker, and M. J. Kim, "Magnetically-controlled modular cubes with reconfigurable self-assembly and disassembly," IEEE Transactions on Robotics, 2021.

This material is based upon work supported by the National Science Foundation under Grant Nos. 1553063 and 2050896.

