Demo: MagMorph: an EPM-based State-Transferable Puzzle Block for Collaborative Entertainment and Education

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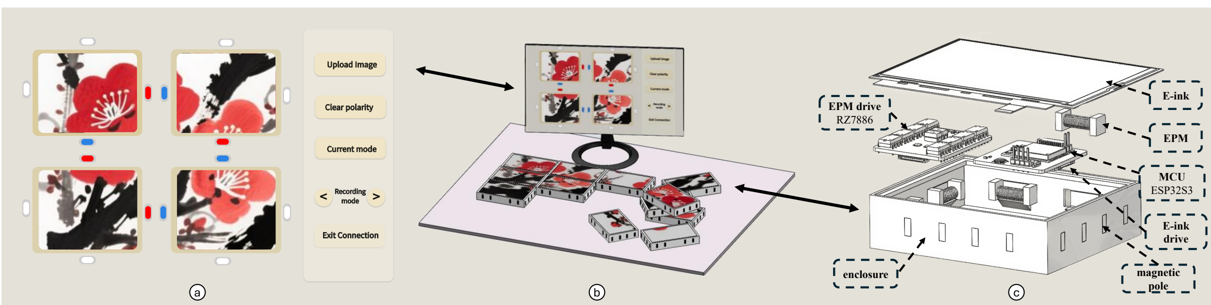

Figure 1: MagMorph: an EPM-based State-Transferable Puzzle Block. (a) user interface (UI) for EPM polarities programming and image segmentation; (b) MagMorph puzzle blocks and UI running on PC; (c) exploded view of the components of MagMorph.

ABSTRACT

We design MagMorph, an Electro-Permanent Magnet (EPM)-based state-transferable puzzle block, used as smart building blocks in educational and intellectual toy domains. MagMorph employs EPMs to generate attraction or repulsion based on the matching of images displayed on its e-ink screen. Its core components include a wireless communication unit, EPMs with a driver module, and an electronic ink (E-Ink) screen with its driver. MagMorph is operated through a host computer's visual user interface, which sends commands via Bluetooth for image segmentation, magnetic force control, and mode switching. Unlike conventional puzzles, MagMorph can record interconnections with other blocks and transfer this state to remote collaborators continuing the puzzle task. In the future, MagMorph will support automated reassembly using a desktop robotic arm to simplify human interaction.

CCS CONCEPTS

• **Human-centered computing** → **User interface programming**.

KEYWORDS

Programmable Block; State-Transferable; Collaborative; Electro Permanent Magnet(EPM)

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1 INTRODUCTION

As computing systems increasingly extend beyond screens and into the physical world, Human-Computer Interaction (HCI) has embraced new paradigms of tangible and shape-changing interfaces to bridge digital information with physical experience. Researchers have explored how reconfigurable physical systems can augment cognition, enable embodied interaction, and support more expressive input/output modalities [2]. However, despite advances in actuated surfaces, modular robotics, and shape displays, current platforms often suffer from high energy demands, limited scalability, and cumbersome mechanical complexity—posing challenges for real-world deployment in educational, industrial, or adaptive environments [3]. To address these limitations, we propose MagMorph, a low-power block built upon electro-permanent magnet (EPM) that enables users to physically reconfigure modules through programmable magnetic connections.

2 MAGMORPH IN A NUTSHELL

MagMorph is designed as an intelligent building block system to enable applications in smart toys and educational tools [1]. Each MagMorph block comprises six components: an electronic ink (E-Ink) screen, an ESP32 module for central control and BLE communication, electro-permanent magnets (EPMs), an EPM driver board, and a battery. Using the custom-designed UI software, any image can be uploaded, segmented, and assigned to individual MagMorph

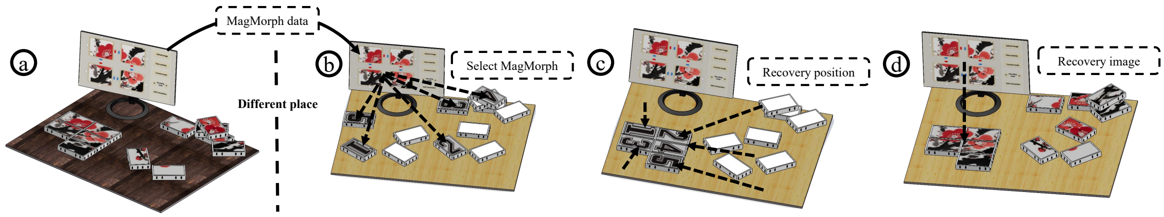

Figure 2: (a)The player completes part of the puzzle. (b) Give numerical guidance to help. (c) Position parts of the puzzle. (d) The new player continues to complete the puzzle.

blocks for display on the E-Ink screens. The UI also allows players to reconfigure the polarity of the EPMs on each side of the MagMorph block. MagMorph uses EPMs to enable attraction and repulsion between modules. Puzzle correctness can be inferred visually via the E-Ink displays or tangibly through magnetic force feedback [4]. The interconnection of MagMorph is illustrated in Fig. 3.

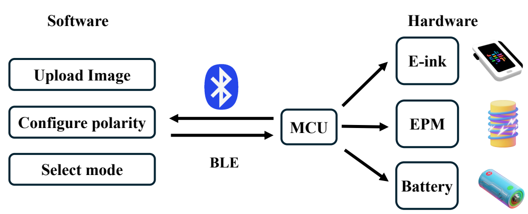

Figure 3: MagMorph system interconnection.

2.1 State Transfer for Collaborative Tasks

The configured polarities of the EPMs can be stored by the UI software and transferred to remote players who also own MagMorph, allowing them to continue the remaining puzzle tasks at a different location. As shown in Fig.2, player A, using a dark table, can transfer the MagMorph data—which includes the connections of the partially completed blocks and their corresponding image assignments—to player B at another location (Fig.2a). When player B, on a light-colored table, is ready to resume, the MagMorph software provides UI instructions to pick the blocks previously completed by player A, with numbered hints displayed on the E-Ink screens (e.g., 1, 2, 3, ...) as shown in Fig.2b, and visual guidance on the connection orientations of each block (Fig.2c). Once confirmed by player B, the corresponding image segments are loaded onto each block (Fig. 2d). This *State Transfer* feature enables collaborative puzzle solving with friends across any distance.

2.2 Energy Efficiency for Long Lifespan

MagMorph is designed for low-power operation, integrating both E-Ink displays and electro-permanent magnets (EPMs). The E-Ink display consumes approximately 8 mA during image updates and nearly zero current in standby mode. Each update takes around 12–15 seconds. The EPMs require a high current of 10–20 A for a brief duration (300 µs) to switch magnetic polarity from −100 mT to +100 mT. By applying duty-cycle optimization techniques, the average communication current can be reduced to below 50 µA. Assuming one E-Ink update and ten EPM polarity changes per side per day, the total energy consumed daily is less than 0.54 coulombs. With a 300 mAh battery, MagMorph can operate for nearly 5.48 years under this usage pattern.

3 POTENTIAL APPLICATIONS

MagMorph blocks enable interactive, rule-aware gameplay by acting as smart game tokens that store identity and enforce connection logic through programmable magnetism. One application is *poker-style games*, where each block functions as a playing card displayed on its E-Ink screen. Players build hands, place bets by attaching blocks to a pot, and the blocks retain game state for evaluation, replay, and sharing. A 3D version of MagMorph also supports *collaborative world-building*, with each block representing terrain, structures, or characters. As players connect blocks to build worlds, the modules store their role and interactions, enabling evolving creations for storytelling, education, and play.

4 CONCLUSION AND FUTURE WORK

This paper presents MagMorph, an EPM-based puzzle block with state transfer capability. The system integrates image display, magnetic force control, and wireless communication to enable programmable, intelligent interaction for smart construction toys. Future work will focus on two directions. First, we plan to develop an automated reassembly system, potentially using a desktop robotic arm, to reconstruct blocks at the remote site. Second, we aim to extend MagMorph into a 3D platform, enabling a wider range of applications.

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